Approved afforestation and reforestation baseline methodology AR-AM0002

"Restoration of degraded lands through afforestation/reforestation"

Source

This methodology is based on the draft CDM-AR-PDD "Moldova Soil Conservation Project" whose baseline study, monitoring and verification plan and project design document were prepared by the Moldsilva, The State Forest Agency of Moldova, the Forest Research Institute, Moldova; GFA Terrasystems, Germany; Winrock International, Washington DC; and World Bank reviewers. For more information regarding the proposal and its consideration by the Executive Board please refer to case ARNM0007-rev: "Moldova Soil Conservation Project" at http://cdm.unfccc.int/methodologies/ARmethodologies/process?OpenNM=ARNM0007&single=1.

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

1. Selected baseline approach from paragraph 22 of the CDM A/R modalities and procedures

"Existing or historical, as applicable, changes in carbon stocks in the carbon pools within the project boundary."

2. Applicability

This methodology is applicable to project activities with the following conditions:

- The project activity does not lead to a shift of pre-project activities outside the project boundary, i.e. the land under the proposed A/R CDM project activity can continue to provide at least the same amount of goods and services as in the absence of the project activity;
- Lands to be reforested are severely degraded (due to such agents as soil erosion, land slides, or other physical constraints as well as anthropogenic actions) and the lands are still degrading;
- Environmental conditions or anthropogenic pressures do not permit significant encroachment of natural tree vegetation;
- Grazing will not occur within the project boundary in the project case;
- The application of the procedure for determining the baseline scenario in section II.4 leads to the conclusion that the baseline approach 22(a) (existing or historical changes in carbon stocks in the carbon pools with the project boundary) is the most appropriate choice for determination of the baseline scenario and that the land would remain degraded in the absence of the project activity.

3. Selected carbon pools:

Table 1: Selection and justification of carbon pools

Carbon Pools	Selected (answer with yes or no)	Justification / Explanation
Above ground	Yes	Major carbon pool subjected to the project activity
Below ground	Yes	Major carbon pool subjected to the project activity
Dead wood	Yes	Carbon pool subjected to the project activity
Litter	Yes	Carbon pool subjected to the project activity
Soil organic carbon	Yes	Carbon pool subjected to the project activity

4. Summary of baseline and monitoring methodologies

Baseline methodology steps:
This methodology is applicable for a proposed A/R project activity on degraded lands.

The methodology applies the baseline approach 22 (a) for the proposed A/R CDM project activity, taking into account historical land use/cover changes, national, local and sectoral policies that influence land use within the boundary of the proposed A/R CDM project activity, economical attractiveness of the project relative to the baseline, and barriers for implementing project activities in absence of CDM finance.

The proposed A/R CDM project area is stratified taking into account the local site classification criteria, the most updated land use/cover maps or satellite imagery, soil map, vegetation map, landform map and supplementary surveys. The baseline scenario is determined separately for each stratum. For strata without growing trees, this methodology conservatively assumes that the carbon stocks would remain constant in the absence of the project, i.e., the baseline net GHG removals by sinks are zero. For strata with a few growing trees, the baseline net GHG removals by sinks are estimated based on methods in GPG-LULUCF[1]. The loss of non-tree living biomass due to competition from planted trees or site preparation is accounted as an emission within the project boundary.

This methodology uses the latest version of the "Tool for the demonstration and assessment of additionality for afforestation and reforestation CDM project activities[2] "
In cases where public or private entities implemented A/R activities prior to the project, the methodology presents provisions to account the GHG removals by sinks from the pre-project A/R activities as part of the baseline.

The methodology invites to use location specific data, published literature, empirical methods, expert inputs from national forest management agencies and the Good Practice Guidance on LULUCF (IPCC 2003) in the ex-ante estimation of carbon stock changes. The steps and methods of this methodology are applicable to both empirical methods and peer reviewed models to estimate carbon stock changes under the ex-ante project scenario[3].

The methodology estimates the GHG removals by sinks and identifies the sources of emissions in terms of emissions from fossil fuel use, loss of biomass in site preparation, burning of biomass, and application of fertilizes under the project scenario. It presents methods to quantify emissions from each source. Furthermore, the methodology identifies the sources of leakage and presents methods to account the leakage associated with the project.

This methodology adopts the equations, nomenclature, variables, and notation of AR-AM0001 for the above-ground and below-ground biomass pools, project emissions and leakage covered under that

[1] Throughout this document, "GPG-LULUCF" means the Good Practice Guidance for Land Use, Land Use Change and Forestry from the Intergovernmental Panel on Climate Change (2003). This document is available at the following URL: http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm.

[2] Throughout this document, "A/R additionality tool" refers to the document approved by the Executive Board of the CDM and is available at http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html.

[3] It is possible to use this methodology with the empirical methods or peer reviewed models. In other words, the steps and methods represented in the form of equations in this methodology can be implemented either in a spreadsheet format or by using a peer reviewed model (e.g.,CO2FIX).

approved AR methodology. Additionally, this methodology presents methods for estimation of carbon stock changes in the three remaining carbon pools – deadwood, litter and soil organic carbon, and outlines methods for ex-ante estimation of changes in the carbon pools using the empirical methods or peer-reviewed models.

This choice of empirical methods or peer-reviewed models under this methodology enhances its reach to project participants that prefer either method. Furthermore, the use of empirical methods as stand alone or as complements to a peer reviewed model for the purpose of *ex-ante* estimation of carbon stock changes improves the scope of the methodology.

However, the reference to a model for the *ex-ante* estimation under this methodology is intended to facilitate the project participants' use of only peer reviewed models that are widely available and can be accessible free of charge. The demonstration of the applicability of this methodology to peer reviewed models does not constitute an endorsement of any specific model.

<u>Monitoring methodology steps:</u>

This methodology includes the following elements:

- Monitoring of the overall performance of the proposed A/R CDM project activity, including the integrity of the project boundary and the success of forest establishment and forest management activities;
- Monitoring of the actual net GHG removals by sinks, increases in GHG emissions within the project boundary due to nitrogen fertilization, use of machinery, and removal of non-tree vegetation and burning of biomass in site preparation activities;
- Monitoring of leakage from the use of vehicles in the transportation of staff, seedlings, timber and non forest products, as a result of the implementation of the A/R CDM project activity;
- A Quality Assurance/Quality Control plan that covers field measurements, data collection, verification, data entry and archival, as an integral part of the monitoring plan to improve the monitoring efficiency and to ensure the integrity of data collected in the A/R CDM project activity.

The baseline net GHG removals by sinks do not need to be measured and monitored over time. However, the methodology checks and re-assesses assumptions at the renewal of the crediting period. This methodology stratifies the project area based on local climate, existing vegetation, site class, and tree species and years or groups of years in which plantings are undertaken. Data from land use/cover maps, satellite images, soil maps, GPS or field survey are considered in the stratification. The methodology requires the use of permanent sample plots to monitor the carbon stock changes in the biomass pools, and use of either temporary or permanent sample plots to monitor the soil pool. The methodology first determines the number of plots needed in each stratum/sub-stratum to reach the targeted precision level of ±10% of the mean at the 95% confidence level.

The methodology provides guidance for:

a) *Monitoring and measurement of carbon stocks*: The plots identified and demarcated as per the sample frame shall be monitored and measured at specified intervals:

   - *Vegetation monitoring*: The methodology requests to monitor the above-ground vegetation, deadwood, and litter using permanent sample plots at 5-year intervals. It offers formulae for the calculation of sample size and outlines methods for allocation of sample plots and as well as their location in the strata and the sub-strata;

- *Soil monitoring*: The methods of soil monitoring assess the changes in soil carbon status with reference to the soil carbon stock at the beginning of the project. The methodology recommends between 10-year to 20 year monitoring interval for monitoring the soil carbon pool.

b) *The emissions* associated with the use of fossil fuels in the *project* activities, loss of biomass in the site preparation, burning of biomass and fertilizer application are monitored throughout the project period and calculated from the monitoring data.

c) *Quality assurance of monitoring activities*: The procedures related to measurement, collection of data, and data entry and data storage should be implemented by following the standard operating procedures to improve the monitoring efficiency and to ensure the integrity of the data collected.

Section II. Baseline methodology description

1. Eligibility of land

This methodology uses the latest version of the mandatory tool: "Procedures to define the eligibility of lands for afforestation and reforestation project activities" approved by the CDM Executive Board to demonstrate land eligibility within the project boundary.

2. Project boundary

The A/R CDM project activity may contain more than one discrete parcel of land. Each discrete parcel shall have a unique geographical identification. The boundary shall be defined for each discrete parcel and delineated to make the boundary geographically verifiable. The plot data shall be recorded, archived and listed in the CDM-AR-PDD. The emission sources and gases foreseen in the project boundary are listed in the table below.

Table 2: Gases considered from emissions by sources

Source	Gas	Included/ excluded	Justification / Explanation
Burning of fossil fuels	CO_2	Included	
	CH_4	Excluded	Potential emission is negligibly small
	N_2O	Excluded	Potential emission is negligibly small
Burning of biomass	CO_2	Included	
	CH_4	Included	
	N_2O	Included	
Use of fertilizers…	CO_2	Excluded	Not applicable
	CH_4	Excluded	Not applicable
	N_2O	Included	

3. Ex-ante stratification

In general, the conditions of the ex-ante stratification can be different from the ex-post stratification. Therefore, the steps presented below are intended to facilitate the ex-ante stratification.

The guidelines presented below are intended to facilitate the *ex-ante* stratification. The stratification of the baseline and the project scenarios is represented under strata *i,* sub-strata highlighting the age class *j*, and species *k*, with the respective subscript references for the baseline (BL) and the project (PJ) contexts.

Stratification under baseline scenario

The baseline scenario comprises bare lands or lands with sparse vegetation that are below the thresholds of the definition of forest. The area corresponding to the baseline should be stratified taking into account physiographic variables, pre-project vegetation, soil characteristics, and anthropogenic influences on the land use. The procedures to be followed in the *ex-ante* stratification are:

Step 1: Collect information on the land use from official reports, maps, remote sensing images, and published literature demonstrates the historic and current land use and land cover patterns.

Step 2: Conduct preliminary stratification taking into account pre-existing conditions and anthropogenic influences on the baseline carbon stocks in the following contexts:

- bare lands that highlight physiographic features and other constraints that limit the occurrence of natural vegetation should be assessed (3 to 5 plots shall be used for each preliminary stratum to collect information on the characteristics of bare lands);
- lands with sparse vegetation can have widely varying levels of vegetation comprising herbs, shrubs, and scattered woody vegetation that is well below the thresholds of the forest. Data from 3 to 5 plots per each preliminary stratum shall be used to demonstrate the inability of the area to regenerate by natural means; and
- information on anthropogenic influences shall be assessed by collecting information on the land use and the products harvested.

Step 3: Conduct field surveys based on preliminary stratification to characterize the carbon pools:

- above-ground vegetation – scattered tree and non-tree vegetation shall be surveyed to assess the variability of above-ground biomass. In case of scattered vegetation, the numbers and diameters of trees shall be noted in order to demonstrate the sparseness of the vegetation;
- non-tree vegetation - herb and shrub vegetation shall be assessed by measuring and evaluating 10 or more plots (systematically located with random start) of the size of 2 to 4 m^2 per preliminary stratum to assess the growth of non-tree vegetation;
- deadwood – the deadwood component is likely to be either absent or insignificant in degraded lands and is not likely to influence the baseline stratification, therefore, it can be ignored in the ex-ante stratification;
- litter – small amounts of above-ground vegetation in degraded lands is expected to result in insignificant quantities of litter. Therefore, it has no influence on the stratification of the baseline; and
- soil – the soil type, depth, gradient, intensity of erosion, drainage and other characteristics should be considered in the baseline stratification. Depending on the nature and extent of land degradation, soil pool can have a major influence on the baseline stratification;
- Data on pre-existing conditions and carbon pools should be taken into account in the stratification of the baseline scenario;

- The variation within and between strata shall be assessed in order to adopt representative number of strata and to divide the strata into sub-strata. If variation within the stratum exceeds the threshold chosen for stratification, the strata shall be divided into two or more sub-strata;
- Mapping of the strata shall be done taking into account the information on topography, soils, and vegetation to reflect the status of carbon pools.

Stratification under the ex-ante project scenario

The number of species included in the project scenario and the diversity of management practices will influence the actual net greenhouse gas removals by sinks. Therefore, the ex-ante stratification of the project scenario should be based on the following considerations:

- Silvicultural characteristics of vegetation that reflect in the differences between species or species groups:
    - geographic distribution of species, their composition and characteristics that highlight the native and non-native species;
    - number of species proposed to be included in the project, their growth rates, competition, and rotation cycles;
- Management requirements of species or species groups proposed under the project scenario[4]:
    - area proposed to be planted by species or species group, and the year of planting in order to categorize into age classes for categorization into sub-strata;
    - management practices such as planting or seeding, thinning, fertilization, harvesting, and replanting cycles; and
    - intensity of management in terms of labour requirements for weeding, thinning, and harvest or the need for purchased inputs such as fertilizers, pesticides etc.
- Site productivity and soil characteristics that can reflect the evolution of the carbon stocks over time:
    - site productivity that influence the rate of change in the soil carbon pool; and
    - soil characteristics such as texture, aspect, depth, drainage, and slope etc.

4. Procedure for selection of most plausible baseline scenario

Project participants should determine the most plausible baseline scenario using the following steps:

Step 1: Identify and list plausible land uses including future public or private activities on the degraded lands such as any similar A/R activity or any other feasible land development activities, considering relevant national or sectoral land-use policies that would impact the project area. The information from land records, or field surveys, or feedback from stakeholders, or other appropriate sources shall be used.

Step 2: Demonstrate that under the scenarios identified in Step 1, the most plausible scenario is that the project areas would remain degraded in absence of the project activity however, small rates of afforestation (pre-project A/R activity undertaken historically) which can be expected to continue in the absence of the project could occur. In this context, attractiveness of the alternative land uses,

[4] Since this methodology uses CO2FIX model, species, management, soil criteria reflect in the input and outputs requirements of a stand models and the evolution of carbon pools in the CO2Fix model.

benefits to project participants, feedback from stakeholders of the land use, and the barriers associated with the alternative land use shall be evaluated in one of the following ways:

- **Generally**: By demonstrating that similar lands, in the vicinity, are not planned to be used for the alternative land uses and the financial or other barriers, which prevent alternative land uses can be identified;
- **Specifically for a forest as an alternative land use:** Apply step 2 (investment analysis) or step 3 (barrier analysis) of the A/R "Tool for the demonstration and assessment of additionality", to demonstrate that the land use in the absence of the CDM, is unattractive;
- **Specifically for any agricultural alternative land use**: Demonstrate that the project lands have restrictions on the agricultural uses. Alternatively, use step 2 of the A/R "Tool for the demonstration and assessment of additionality" to demonstrate that alternative agricultural land uses are financially non-viable, or other barriers to agricultural uses exist.

Step 3: To support the above findings, demonstrate that the lands to be planted[5] are really "degraded" by applying the Step 3a and Step 3b below:

Step 3a: Analyze the historical and existing land use/cover changes in a social-economic context and identify key factors that influence the land use/cover changes over time, using multiple sources of data from archives, maps or satellite images of the land use/cover around 1990 and before the start of the proposed A/R CDM project activity, field surveys, interviews, and collection of data from other sources. The historical land degradation can be demonstrated using one or more of the following indicators:

- Vegetation degradation, e.g.,
  - crown cover of non-tree vegetation has decreased in the recent past for reasons other than sustainable harvesting activities;
- Soil degradation, e.g.,
  - soil erosion has increased between two time points in the recent past;
  - soil organic matter content has decreased between two time points in the recent past.
- Anthropogenic influences, e.g.,
  - history of loss of soil and vegetation due to anthropogenic actions; and
  - anthropogenic actions adversely impact the establishment of natural regeneration.

Step 3b: Evidence that shows that the lands are not expected to regenerate naturally and would continue to remain ***degraded*** or ***degrade further*** in the absence of the project activity. For this purpose, project participants shall demonstrate that there is a lack of:

(a) on-site seed pool that may result in natural regeneration;
(b) external seed sources that may result in natural regeneration;
(c) possibility of seed sprouting and growth of young trees;

This may, for example, be done through surveys of the project areas and surrounding areas for two different years over a ten-year period or by other means that clearly demonstrate

[5] This section interprets the term "degradation" only in the context of non-forest land, subject of this methodology. Degradation of existing forests is not covered. Therefore the definition of degradation is more constrained than in the IPCC report on "Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types, see <http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/degradation.htm>.

impossibility of natural regeneration in a credible and verifiable way.

Step 4: These can represent the degraded bare lands, degraded lands in various stages of degradation, degraded lands with isolated vegetation, or degraded lands on which small rates of afforestation that occurred prior to the project and can be expected to continue in the future. It should be demonstrated that the candidate baseline scenarios do not alter the historical land use patterns of degraded lands, by providing the evidence outlined below.

- Lands do not show significant deviation from the historical land use pattern. To evaluate the deviation in land use, the project participants shall use the data on land use practices, economic policies, and market variables over the most recent 10-year period;
- Demonstrate that the national or sectoral land-use policies adopted prior to 11 November 2001 do not influence the areas of the proposed A/R CDM project activity (e.g., because the policy is not implemented, the policy does not target this area, or because there are prohibitive barriers to the policy in this area, etc.

Step 5: Confirm that the most plausible land use chosen as the baseline does not lead to an increase in the carbon stocks or other profitable uses.

- The project participants should consider the data on vegetation, soil, physiography (slope, aspect, altitude etc.) and land use over a 10-year period prior to the project;
- Project participants should show that the changes in adjoining land use are not likely to lead to more profitable alternative(s) over the next 5 year period(e.g. conversion to other uses due to urbanization) or shifts to other land uses that could be attributable to recent government policies or regulation (e.g. tax incentives).

This methodology is not applicable, if the project proponents can not clearly show in the application of Steps 1 to 5 that the baseline approach 22(a) (existing or historical changes in carbon stocks in the carbon pools within the project boundary), and the scenario “lands to be planted are degraded lands and will continue to degrade in absence of the project” is the most appropriate plausible baseline scenario.

To ensure transparency, all information used in the analysis of the baseline scenario shall be archived.

5. Estimation of baseline net GHG removals by sinks

The methodology recognizes two possible land uses in the baseline scenario - (*i*) degraded bare lands or degraded lands that have vegetation much below the thresholds (area, crown cover, and tree height) of forest defined by the DNA, and (*ii*) degraded lands on which small rates of afforestation occurred prior to the project (pre-project A/R activity undertaken historically) and can be expected to continue in the absence of the project.

(i) Degraded bare lands and degraded lands

For degraded bare lands or degraded lands with sparse non-woody or isolated pre-project vegetation, the *baseline net GHG removals by sinks* are set to zero for the first crediting period. The degraded lands with sparse vegetation have vegetation thresholds (area, height, and crown cover) much below those defined for forest by the DNA and the baseline net GHG removals by sinks are expected to show low steady state level of carbon stock or long-term negative changes in the carbon pools and can be confirmed by the data and the provisions of baseline approach 22(a).

The baseline net GHG removals by sinks on such lands shall be set to zero and represented as follows.

$$\Delta C_{BDL\,ijk,t} = 0 \qquad \textbf{(B.1)}$$

where:

$\Delta C_{BDL,ijk,t}$ average annual change in the carbon stocks of bare lands or degraded lands with sparse pre-existing vegetation in stratum *i* substratum *j* species *k* in t CO_2 yr^{-1} set to zero (net baseline GHG removals by sinks are expected to be negligible during the crediting period).

i stratum of the baseline 1,2,3…*i*

j substratum of the baseline 1,2,3…*j*

k species of the baseline 1,2,3,...*k*

t 1 to length of crediting period

Since all pools in the degraded lands under the baseline scenario are expected to decline, it is conservative to set the net change in the carbon stocks to zero. For areas with isolated trees, the changes in carbon stocks of the living biomass shall be estimated for isolated trees and the baseline net GHG removals by sinks shall be calculated as follows:

$$\Delta C_{BDL_{ijk,t}} = \Delta C_{BDL\_LB_{ijk,t}} \qquad \textbf{(B.2)}$$

where:

$\Delta C_{BDL\_LB_{ijk,t}}$ sum of annual changes in the carbon stocks of living biomass (above- and below-ground) in stratum *i* substratum *j* species *k* in t CO_2 yr^{-1}

The sum of changes in the living biomass estimated as part of the baseline study prior to the project shall be frozen and adopted as the baseline under the assumption that the vegetation will degrade further in the absence of the project. The net changes in the carbon stocks of deadwood, litter and soil are expected to be negative. Therefore, it is conservative to set the net changes in these pools to zero.

The baseline adopted at the start of the project shall remain valid throughout the crediting period and not required to be monitored. The confirmation of this baseline for the subsequent crediting periods is subject to the renewal conditions applicable for the subsequent periods. The re-evaluation of the baseline should be conducted at the end of the first crediting period as per the applicable EB decisions and guidance in this regard.

(ii) *Degraded lands with pre-project A/R*

In this scenario, small amounts of A/R activities undertaken in the region historically (e.g., over previous 10 year period) on lands that are similar to the degraded lands of the project area are expected to continue in the absence of the project at an average annual rate of pre-project A/R. The biomass removals from the pre-existing A/R activity shall be treated as part of the baseline scenario[6].

Under this methodology, the annual average area under the pre-project A/R is estimated from the data on the pre-project A/R that occurred over the previous 10-year period or a period longer than 5 years of the 10 previous years over which data are available. The baseline net GHG removals by sinks corresponding to the annual average area under the pre-project A/R shall be calculated and included as part of the baseline before the *ex-ante* baseline is adopted under the baseline approach 22(a), and frozen for the crediting period.

The steps to be followed in estimating the baseline net GHG removals corresponding to the pre-project A/R are outlined below:

Step 1: If the project participants have undertaken A/R activity in the pre-project period, the average annual area of degraded lands afforested during the previous 10-year period shall be calculated. In the case of public agencies, official reports on the annual A/R shall be used. In the case of private entities, annual reports or land records or other official and verifiable documents shall be used to estimate the annual rate of pre-project A/R relevant to the project entity.

Step 2: If information on the pre-project A/R activity of project participants is not available, the percent of land area corresponding to the average annual pre-project A/R undertaken at the national level during the previous 10-year period relative to the total non-forest area that is eligible for undertaking the A/R activity shall be calculated.

Step 3: The area of pre-project A/R from the above two steps shall be compared and the higher of the two values estimated under step 1 and step 2 shall be used as the baseline pre-project A/R relevant to the project participants. This will ensure the transparent assessment of the pre-project A/R.

Step 4: To estimate the baseline GHG removals by sinks from the pre-project A/R, the species composition of the pre-project A/R activity shall be evaluated. If the species used in the pre-project A/R are common to the species used in the project scenario. The baseline GHG removals by sinks from the pre-project A/R should be estimated following the steps and methods outlined for the *ex-ante* estimation of the actual net GHG removals by sinks in section 7 (a.1.1).

If the species of the pre-project A/R differ from those of the project, the estimation methods and equations used under the project scenario shall still be relevant. The average annual area of the pre-project A/R should be converted into biomass using allometric equations or volume increment of the most widely planted species and their biomass expansion factors.

Step 5: The changes associated with the soil carbon pool under the pre-project A/R shall be estimated following the steps outlined for the *ex-ante* estimation of changes in the soil carbon under the project scenario outlined in section 7 (a.5).

[6] In case the pre-project A/R is not likely to be part of the baseline scenario under certain justifiable circumstances, the project participants shall provide justification by providing project-specific information on why the baseline scenario is not affected by the actual level of pre-project A/R activities on the degraded lands that are expected to continue in the region/country in future. In all other cases, treatment of pre-project A/R should be as per the procedure outlined in this methodology.

Step 6: The changes in non-tree biomass, deadwood, and litter pools for the pre-project A/R shall be set to zero since these pools are likely to increase under the pre-project A/R, therefore, such a treatment is justified.

Pre-project A/R undertaken as part of the baseline shall be estimated as below.

$$\Delta C_{BAR_{ijk,t}} = [\Delta C_{BAR\_LB\_Tree_{ijk,t}} + \Delta C_{BAR\_S_{ijk,t}}] \quad \textbf{(B.3)}$$

where:

$\Delta C_{BAR_{ijk,t}}$ average annual change in the carbon stocks of pre-project A/R attributable to stratum *i* sub-stratum *j* species *k* in t CO_2 yr^{-1}. (Considering the small amounts of pre-project A/R activity, the sum of changes in the carbon stock of non-tree biomass ($\Delta C_{BAR\_NT_{ijk,t}} = 0$), dead wood ($\Delta C_{BAR\_DW_{ijk,t}} = 0$) and litter ($\Delta C_{BAR\_L_{ijk,t}} = 0$) are expected to increase, therefore it is conservative to set them to zero.

$\Delta C_{BAR\_LB\_Tree_{ijk,t}}$ average annual change in the carbon stocks of living tree biomass pools (above-ground and below-ground tree biomass) of the pre-project A/R attributable to stratum *i* sub-stratum *j* species *k* in t CO_2 yr^{-1} .

$\Delta C_{BAR\_S_{ijk,t}}$ average annual change in the carbon stocks of soil pool of the pre-project A/R attributable to stratum *i* sub-stratum *j* species *k* in t CO_2 yr^{-1}

Note: Strict demarcation of pre-project A/R into baseline strata is not possible when it is implemented over a large region. In such case, average annual GHG removals from the pre-project A/R shall be estimated based on the area, and mean carbon stock per ha of the species. The methods and equations outlined *for ex-ante* estimation of carbon stock changes in the above-ground tree biomass and soil pool in the Section 7 (a.1.1) can be used to estimate the carbon stock changes of the living tree biomass and soil organic carbon of the pre-project A/R

Baseline net GHG removals by sinks

To determine the baseline net GHG removals by sinks, the following steps shall be followed:

a) Determination of the sum of changes in carbon stock for each stratum:

- For the strata without growing trees, the sum of carbon stock changes in all carbon pools covered under this methodology is set as zero;
- For the strata with growing trees, the sum of carbon stock changes in above-ground and below-ground biomass is determined based on the data from growth models (yield tables), allometric equations, and local or national or IPCC parameters; and
- For strata that relate to the pre-project A/R, the changes in carbon stock of living tree biomass and soil pools shall be estimated following the methods and equations outlined for *ex-ante* estimation in the Section 7 (a.1.1).

b) Sum of the baseline net GHG removals by sinks across all strata.

The baseline net GHG removals of the pre-project A/R should be summed over the period corresponding to the project scenario to maintain consistency between the baseline net GHG removals by sinks and the actual net GHG removals by sinks.

The baseline net GHG removals shall be estimated as follows.

$$\Delta C_{BSL,t} = \sum_{i}\sum_{j}[\sum_{k}\Delta C_{BAR_{ijk,t}} + \Delta C_{BDL_{ijk,t}}] \quad \textbf{(B.4)}$$

where:

$\Delta C_{BSL,t}$ baseline net GHG removals by sinks in year *t* in t CO_2eq yr^{-1}

Methods to estimate the changes in carbon stocks

Changes in the carbon stock of living biomass of trees

Methods to estimate the changes in each pool are relevant to both the baseline and the project scenarios. Depending on the availability of data, carbon gain-loss or stock change methods shall be used to estimate the changes in the carbon pools.

Method 1 (Carbon gain-loss or Default method)[7]

The **gain-loss** method is used to estimate the carbon stock changes of pools as the difference between the gain from the biomass growth and the loss from the harvests and disturbance.

When peer reviewed models are used, the models project carbon stock changes in the time steps of 1 year taking into account the biomass growth and the loss from harvests and disturbance (e.g. fire and pest outbreaks) during the year. (e.g. the use of gain-loss method is implicit in the projections of the CO_2FIX model for the carbon pools covered in this methodology).

$$\Delta C_{ijk,t} = (\Delta C_{G,ijk,t} - \Delta C_{L,ijk,t}) \quad \textbf{(B.5)}$$

where:

$\Delta C_{ijk,t}$ average annual change in carbon stock in stratum *i* sub-stratum *j* species *k* in t CO_2eq yr^{-1}

$\Delta C_{G,ijk,t}$ average annual growth in carbon *stock* for stratum *i* sub-stratum *j* species *k* in t CO_2eq yr^{-1}

$\Delta C_{L,ijk,t}$ average annual loss in carbon *stock* for stratum *i* sub-stratum *j* species *k* in t CO_2eq yr^{-1}

Note: (1) The net changes in all pools are expected to be negative in the baseline scenario of degraded lands. Therefore, the living tree biomass pool is the only pool that is relevant in situations that have pre-project afforestation and the gain-loss method can be used for assessing the changes in the carbon stocks of living biomass of trees.

(2) With regard to the losses of carbon stocks in the baseline, this methodology conservatively assumes $\Delta C_{L,ijk,t} = 0$ for the crediting period[8].

[7] Based on Equation 3.2.2, Equation 3.2.4 and Equation 3.2.5 of GPG/LULUCF

[8] This assumption implies that the baseline biomass is expected to remain the same during the entire crediting period. This is conservative because the proportion of living above-ground biomass that transforms into deadwood or will be harvested is not deducted from the estimation of the baseline net GHG removals by sinks under this methodology.

$$\Delta C_{G\_LB\_Tree,ijk} = [\ \Delta G_{Mean\_LB\_Tree,ijk}\ ] \bullet A_{ijk} \bullet CF_k \bullet 44/12 \quad \textbf{(B.6)}$$

where:

A_{ijk}	area of stratum *i* sub-stratum *j* species *k* in ha
$\Delta G_{G\_LB\_Tree,ijk}$	annual increment of total dry biomass of living trees for stratum *i* sub-stratum *j* species *k* in t.d.m. yr^{-1}
$\Delta G_{Mean\_LB\_Tree,ijk}$	average annual increment of total dry biomass of living trees for stratum *i* sub-stratum *j* species *k* in t.d.m. $ha^{-1}\ yr^{-1}$
CF_k	carbon fraction of the biomass for species k in t C $(t.d.m.)^{-1}$
44/12	ratio of molecular weights of CO_2 and carbon, dimensionless

$$\Delta G_{Mean\_LB\_Tree,ijk} = G_{w,ijk} \bullet (1 + R_{jk}) \quad \textbf{(B.7)}$$

$$G_{w,ij,t} = I_{v,ij} \bullet D_k \bullet BEF_{1,jk} \quad \textbf{(B.8)}$$

where:

$G_{w,ijk}$	average annual aboveground dry biomass increment of living trees for stratum *i* sub-stratum *j* species *k* in t.d.m. $ha^{-1}\ yr^{-1}$
R_{jk}	root-shoot ratio for species *k* age class *j,* dimensionless. The root-shoot ratio may change as a function of the above-ground biomass present in year *t* (refer to IPCC GPG, 2003, Annex 3.A1, Table 3A1.8)
$I_{w,jk}$	average annual increment in merchantable volume for stratum *i* sub-stratum *j* species *k* in $m^3\ ha^{-1}\ yr^{-1}$
D_k	basic wood density for species *k* in t.d.m. m^{-3}
$BEF_{1,ijk}$	biomass expansion factor for conversion of annual net increment (including bark) in the merchantable volume to total aboveground biomass increment for species *k* age class *j,* dimensionless

Method 2 (Stock change method)[9]

The **stock change** method (based on equation 3.2.2, chapter 3.2 of GPG of LULUCF)[10] can be used to estimate the carbon stock changes of pools between the two time period intervals, t_1 and t_2 for carbon stock in the biomass (above-ground biomass, below-ground biomass, deadwood, litter) $C_{B,ijk}$ and soil $C_{S,ijk}$ pools.

$$\Delta C_{LB_{ijk}} = (C_{2,LB,ijk} - C_{1,LB,ijk})/T_B \quad \textbf{(B.9)}$$

[9] Based on the Equation 3.2.3 of GPG/LULUCF

[10] Where increment data are available, the carbon gain-loss method outlined in the chapter 3.2 of GPG on LULUCF could be used to estimate the annual changes in the carbon pools.

where:

$\Delta C_{LB,ijk}$	average annual change in the carbon stocks of biomass for stratum *i* sub-stratum *j* species *k* in t C yr^{-1}
$C_{2,LB,ijk}$	carbon stock in the biomass of stratum *i* sub-stratum *j* species *k* calculated at measurement time period 2 in t C
$C_{1,LB,ijk}$	carbon stock in the biomass of stratum *i* sub-stratum *j* species *k*, calculated at measurement time period 1 in t C
T_B	interval in years between measurement periods 2 and 1 to assess the biomass change

Change in the carbon stock of living biomass: tree component

The change in the carbon stock of living biomass pool includes the change in the above- ground and below-ground tree and non-tree biomass) ($\Delta C_{LB,\ ijk}$). The equations to estimate the change in the living biomass of non-tree component follow on the lines of those for the tree component.

$$\Delta C_{LB,ijk} = \Delta C_{LB\_Tree,ijk} + \Delta C_{LB\_NTree,ijk} \qquad \textbf{(B.10)}$$

Since the change in the living biomass of non-tree component is not considered under the baseline scenario, only the equations on the change in the living biomass of tree component are presented below.

$$\Delta C_{LB\_Tree,ijk} = (C_{2,LB\_Tree,ijk} - C_{1,LB\_Tree,ijk}) / T_B \cdot 44/12 \qquad \textbf{(B.11)}$$

$$C_{LB\_Tree,ijk} = C_{AB\_Tree,ijk} + C_{BB\_Tree,ijk} \qquad \textbf{(B.12)}$$

$$C_{AB\_Tree,ijk} = A_{ijk} \cdot V_{ijk} \cdot BEF_{2,jk} \cdot CF_k \qquad \textbf{(B.13)}$$

$$C_{BB\_Tree,ijk} = C_{AB\_Tree,ijk} \cdot R_k \qquad \textbf{(B.14)}$$

where:

$C_{2,LB\_Tree,ijk}$	total carbon stock in living biomass of trees for stratum *i* sub-stratum *j* species *k* calculated at time 2 in t C
$C_{1,LB\_Tree,ijk}$	total carbon stock in living biomass of trees for stratum *i* sub-stratum *j* species *k* calculated at time 1 in t C
T_B	number of years between times 2 and 1
$C_{AB\_Tree,ijk}$	carbon stock in aboveground tree biomass for stratum *i* sub-stratum *j* species *k* in t C
$C_{BB\_Tree,ijk}$	carbon stock in belowground tree biomass for stratum *i* sub-stratum *j* species *k* in t C
A_{ijk}	area of stratum *i* sub-stratum *j* species *k* in ha
V_{ijk}	merchantable volume of stratum *i* sub-stratum *j* species *k* in m^3 ha^{-1}

$BEF_{2,jk}$ biomass expansion factor for conversion of merchantable volume to above-ground tree biomass for age class *j* species *k*, dimensionless

Allometric equations or growth models can also be used to estimate the changes in the living biomass as recommended in the GPG/LULUCF.

$$C_{AB\_Tree,ijk} = A_{ijk} \bullet nTR_{ik} \bullet f_k(DBH,H) \bullet CF_k \bullet (1/1000) \qquad \textbf{(B.15)}$$

where:

$f(DBH,H)$ allometric equation quantifying the relationship between above-ground biomass to the diameter at breast height (DBH) and tree height (H) of tree species *k* in kg tree^{-1}

nTR_{ik} number of trees in stratum *i* species *k* in trees ha^{-1}

Note: Allometric equations produce estimates in kilograms (kg) biomass per tree. The number of trees per hectare is used to extrapolate the tree biomass to per hectare biomass and the factor 1/1000 is used to convert kilograms into tonnes.

The choice of methods depends on the availability of the data on the parameters. The data on $BEF_{2,jk}$, CF_k and R_k are region and species-specific and can be chosen from the local and national species specific data and inventories. Local data shall be drawn from literature and inventory. If the data are not available from local and national sources, data presented in the GPG-LULUCF can be considered.

Changes in the carbon stock of deadwood and litter

Considering the negligible quantities of deadwood and litter in the degraded lands under the baseline scenario, this methodology assumes that the sum of the changes in the carbon stocks of deadwood $\Delta C_{DW,ijk} = 0$, and litter carbon pool $\Delta C_{L,ijk} = 0$, is assumed to be zero for all strata.

Changes in the carbon stock of soil organic carbon

The changes in the carbon stock of soil organic carbon pool for bare and degraded lands and for lands associated with pre-project A/R are expected to be different. Therefore, this methodology proposes the following two approaches to account for changes in the carbon stocks of soil organic carbon in the baseline scenario.

Bare lands and degraded lands

For bare lands and degraded lands with sparse vegetation, the soil organic carbon is expected to decline under the baseline scenario, therefore, this methodology assumes that the sum of changes in the carbon stocks of soil organic carbon pool $\Delta C_{S,ijk} = 0$ is zero for all strata.

Degraded lands subjected to pre-project afforestation/reforestation

The changes in the carbon stock of soil organic carbon for lands subjected to pre-project afforestation shall be estimated following the methods and steps used for the ex-ante estimation of the changes in the soil organic carbon outlined for the project scenario in Section II. 7.

$$\Delta C_{SOC_{ijks}} = (C_{2,SOC,ijk} - C_{1,SOC,ijk})/T_S \qquad \textbf{(B.16)}$$

where:

$\Delta C_{SOC,ijk}$ = annual average change in the carbon stock of soil pool of stratum *i* sub-stratum *j* species *k* in t C

$C_{SOC\,2,ijk}$ = carbon stock in the soil for stratum *i* sub-stratum *j* under species *k* calculated at time 2 in t C

$C_{SOC\,1,ijk}$ = carbon stock in the soil for stratum *i* sub-stratum *j* under species *k* calculated at time 1 in t C

T_S = interval in years between period 2 and 1 to assess the change in soil organic carbon

6. Additionality

This methodology uses the latest version of the "Tool for the demonstration and assessment of additionality for afforestation and reforestation CDM project activities" approved by the CDM Executive Board[11].

7. Ex ante actual net GHG removal by sinks

Ex-ante actual net GHG removals by sinks are estimated using empirical methods or peer reviewed carbon accounting model such as CO_2FIX that confirm to the applicability conditions of this methodology in order to assess the verifiable changes in carbon pools.

This methodology provides for the use of empirical methods as stand alone or as complements to the peer reviewed model for the purpose of *ex-ante* estimation of carbon stock changes. The empirical methods are the methods used in forest inventory and management studies for calculating the merchantable volume or for estimating the biomass. The data from research and published literature that use scientifically accepted empirical methods can be used for the *ex-ante* estimation purposes provided such data are based on valid sampling and statistical procures and are in agreement with the methods, steps and procedures outlined for the estimation of carbon pools under this methodology. For example, species data based on yield tables, allometric equations, growth models, mortality studies, biomass estimation and nutrient cycling studies and local research that confirms to the methods outlined for *ex-ante* estimation of carbon stock changes under this methodology can be utilized.

The steps and methods of estimation of the *ex-ante* actual net GHG removals by sinks using empirical methods are presented in the following sections. The methods for *ex-ante* estimation of carbon stock changes using CO_2FIX model are presented in **Appendix I**.

(a) Verifiable changes in carbon stocks of pools

The average annual carbon stock change in aboveground biomass, belowground biomass, deadwood, litter, and soil organic matter between two monitoring events for stratum *i* sub-stratum *j* species k can be estimated using the two methods outlined below.

[11] Hereinafter referred as "A/R additionality tool". Please refer to <http://cdm.unfccc.int/methodologies/ARmethodologies/approved_ar.html>

(i) The literature and studies using the *empirical methods* report data on annual increment or as stock change. Therefore, either the gain-loss method or the stock change method can be relevant for the data based on empirical methods;

(ii) The annual projections of the *peer-reviewed model* can be used to calculate the *ex-ante* annual carbon stock changes of the individual carbon pools under the project scenario. The model calculates the changes in carbon stocks using gain-loss method as a difference between the annual biomass growth, and loss from turnover, mortality and harvest over 1-year time steps (Appendix I).

$$\Delta C_{ijk,t} = [\Delta C_{AB,ijk,t} + \Delta C_{BB,ijk,t} + \Delta C_{DW,ijk,t} + \Delta C_{L,ijk,t} + \Delta C_{SOC,ijk,t}] \bullet [44/12] \quad \textbf{(B.17)}$$

where:

$\Delta C_{ijk,t}$	average annual change in carbon stock in the pools for stratum *i* sub-stratum *j* species *k* in t CO_2 yr^{-1}in year t
$\Delta C_{AB,ijk,t}$	average annual change in carbon stock in aboveground biomass for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year t
$\Delta C_{BB,ijk,t}$	average annual change in carbon stock in belowground biomass for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year t
$\Delta C_{DW,ijk,t}$	average annual change in carbon stock in deadwood for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year t
$\Delta C_{L,ijk,t}$	average annual change in carbon stock in litter for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year t
$\Delta C_{SOC,ijk,t}$	average annual change in carbon stock in soil organic matter for stratum *i* substratum *j* species *k* in t C yr^{-1} in year t
44/12	ratio of molecular weights of carbon and CO_2, dimensionless

a.1 Changes in the carbon stocks of above-ground biomass

$$\Delta C_{AB,ijk,t} = (C_{AB,ijk,t_2} - C_{AB,ijk,t_1})/T_B \quad \textbf{(B.18)}$$

$$C_{AB,ijk} = (C_{AB\_Tree,ijk} + C_{AB\_NTree,ijk}) \quad \textbf{(B.19)}$$

Or

$$\Delta C_{AB,ijk,t} = (\Delta C_{AB\_Tree,ijk,t} + \Delta C_{AB\_NTree,ijk,t}) \quad \textbf{(B.20)}$$

where:

$C_{AB,ijk,t2}$	carbon stock in aboveground biomass for stratum *i* sub-stratum *j* species *k* calculated at time t_2 in t C
$C_{AB,ijk,t1}$,	carbon stock in aboveground biomass for stratum *i* sub-stratum j species *k* calculated at time t_1 in t C

$C_{AB\_Tree,ijk}$	carbon stock in aboveground biomass of living trees for stratum *i* substratum *j* species *k* in t C
$C_{AB\_NTree,ijk}$	carbon stock in aboveground biomass of non-tree vegetation for stratum *i* substratum *j* species *k* in t C
T_B	number of years between measurement at time t_2 and t_1 for biomass
$\Delta C_{AB\_Tree,ijk,t}$	average annual change in the above-ground tree biomass in stratum *i* sub-stratum *j* species *k* at year t in t C
$\Delta C_{AB\_NTree,ijk,t}$	average annual change in the above-ground non-tree biomass in stratum *i* sub-stratum *j* species *k* at year t in t C

a.1.1. Above-ground biomass: Tree (C_{AB_Tree})

Changes in the carbon stock of tree biomass using empirical methods

If one or more major species dominate the afforestation / reforestation activities of the degraded lands and certain species account for large proportion of the planting stock, the species groups that cover significant proportion of project and have similar growth behaviour can be categorized as species groups. The grouping of species helps to overcome the constraints associated with the lack of yield data for certain species.
It is possible to estimate the carbon stock in the above- and below-ground tree biomass using one of the two methods, i.e., Allometric Equation or Biomass Expansion Factor (BEF) methods. For all trees above the defined minimum diameter, biomass shall be estimated with the use of allometric equations or biomass expansion factors.

- *Allometric Equation method*

Step 1: Identify the local or national allometric equations that are relevant to the species and species types for which above-ground biomass estimation is required.

Step 2: Local or national allometric equations should be considered as a priority. In the absence of local and national data, allometric equations from the Good Practice Guidance on LULUCF relevant to the region in which project is located can be used.

$$C_{AB\_Tree,ijk} = A_{ijk} \bullet nTR_{ik} \bullet f_k(DBH,H) \bullet CF_k \bullet (1/1000) \qquad \textbf{(B.21)}$$

where:

$f_k(DBH,H)$	allometric equation quantifying the relationship between above-ground biomass tree of species *k* in kg tree^{-1} to the diameter at breast height (DBH) and tree height (H) for species *k*, dimensionless. Mean DBH and H values can be estimated for stratum *i* sub-stratum *j* species *k*
$DBH(t),H(t)$	growth/yield table that represents merchantable volume as a function of tree age
A_{ijk}	area of stratum *i* substratum *j* and species *k* in ha
nTR_{ik}	number of trees in stratum *i* species *k* in trees ha^{-1}

CF_k carbon fraction for species k in t C (t.d.m.)$^{-1}$

Note: Allometric equations produce estimates in kg biomass per tree. The number of trees per hectare is used to extrapolate the tree biomass to per hectare biomass and the factor 1/1000 is needed to convert Kg into tonnes.

- *Biomass Expansion Factor method*

Step 1: The stem volume estimates are converted to dry biomass using basic wood density and expansion factors for the species. It must be noted that the basic wood density (D_s) and biomass expansion factors ($BEF_{2,k}$) vary by forest type, age, growing conditions, stand density and climate. It is recommended to use species-specific local, regional, or national parameters for D_s, BEF_{jk}. If local or national parameters are not available, expansion factors from the GPG/LULUCF or published and peer reviewed literature should be used with clear reference to the data sources.

$$C_{AB\_Tree,ijk} = A_{ijk} \bullet V_{ijk} \bullet D_k \bullet BEF_{jk} \bullet CF_k \quad \textbf{(B.22)}$$

where:

$C_{AB\_Tree,ijk}$ above-ground tree biomass in stratum i sub-stratum j species k in t C

V_{ijk} merchantable tree volume in stratum i sub-stratum j species k in m^3 ha^{-1}

D_k basic wood density for species k in t.d.m. m^{-3}

BEF_{jk} biomass expansion factor for species k to convert merchantable volume into above-ground biomass, dimensionless

Step 2: If data on volume increment ($I_{T,jk}$) are available from yield tables, they can be used to estimate the above ground tree biomass increment.

$$\Delta C_{AB\_Tree,ijk} = A_{ijk} \bullet I_{Tree,ijk} \bullet BEF_{2,jk} \bullet CF_k \quad \textbf{(B.23)}$$

where:

$\Delta C_{AB\_Tree,ijk}$ average annual above-ground tree biomass increment for stratum i sub-stratum j species k in t.d.m. ha^{-1} yr^{-1}

$I_{Tree,ijk}$ average annual increment of merchantable timber volume for stratum i sub-stratum j species k in m^3 ha^{-1} yr^{-1}

$BEF_{2,jk}$ biomass expansion factor for conversion of annual increment (including bark) of merchantable volume to above-ground tree biomass increment for species k age class j, dimensionless

a.1.2. Above-ground biomass: Non-tree (Shrub and Herb) (C_{NTree})

The above-ground non-tree biomass comprises shrub or herb components. The shrub component under this methodology refers to non-woody vegetation that is below the minimum diameter and height defined for tree in the country. The initial non-tree biomass in degraded lands is expected to be low depending on the nature and extent of land degradation. The above-ground non-tree biomass is represented as follows.

$$C_{AB\_NTree,ijk} = C_{AB\_NTree\_Shrub,ijk} + C_{AB\_NTree\_Herb,ijk} \quad \textbf{(B.24)}$$

where:

$C_{AB\_NTree\_Shrub,ijk}$ carbon stock in aboveground biomass of shrub for stratum *i* substratum *j* species *k* in t C

$C_{AB\_NTree\_Herb,ijk}$ carbon stock in aboveground biomass of herbs for stratum *i* substratum *j* species *k* in t C

Step 1: Estimation of carbon stock changes in non-tree shrub biomass using empirical methods - allometric equations / accumulation factors

Depending on the composition of native shrubs and shrub species planted in restoring degraded lands, shrub biomass can form significant component of the project. The available local or regional shrub allometric equations shall be collected and their relevance to the project context shall be explored by evaluating the models for their applicability to the project context. For example, the biomass regression for non-tree woody perennials to the height and diameter at 30 cm above-ground is outlined below (Stewart 2002)[12]. It is possible to omit non-tree woody biomass in the ex-ante estimation, provided that this is conservative.

$$B_{AB\_NTree\_Shrub_{ijk}} = \alpha + \beta \bullet \sum D^2{}_{ijk} \bullet H_{ijk} \quad \textbf{(B.25)}$$

$$C_{AB\_NTree\_Shrub_{ijk}} = A_{Shrub\,ijk} \bullet B_{NTree\_Shrub_{ijk}} \bullet CF_S \quad \textbf{(B.26)}$$

Note: the strata *i* substrata *j* and species *k* refer to the tree species with which shrubs are associated.

where:

$B_{AB\_NTree\_Shrub,ijk}$ above-ground non-tree shrub biomass of woody perennials in stratum *i* sub-stratum *j* (age class of tree) species *k* in t.d.m. ha^{-1}.

$D^2{}_{ijk}$ sum of all diameters squared for the woody perennial in stratum *i* sub-stratum *j* (age class of tree) species *k* in cm

H_i height of the woody perennial from base to its tip in stratum *i* sub-stratum *j* (age class of tree) species *k* in m

α intercept

β regression parameter

CF_S carbon fraction for shrub in t C (t.d.m.)$^{-1}$

$A_{Shrub,ijk}$ area of stratum *i* substratum *j* and shrub species *k* in ha

Alternatively, default carbon emission factors can be used, provided the accumulation factors adopted are based on justifiable criteria and supported by relevant studies.

[12] J.L Stewart , A.J.Dunsdon, J. J. Hellin, and C. E. Hughes (2002) Wood Biomass Estimations of Central American Dry Zone Species, *Tropical Forestry Papers* 26, University of Oxford, UK.

If the shrub allometric equations relevant to the project context are not readily available, it is *good practice* to adopt existing allometric equations available for similar species types in the region. The allometric equations for shrubs are based on the shrub variables such as diameter at base (DB), shrub height (H), crown area/diameter (CA) and the number of stems (N)

$$C_{AB\_NTree\_Shrub,_i} = A_{Shrub,i} \bullet f_k(DB, H, CA, N) \bullet CF_s \qquad \textbf{(B.27)}$$

where:

$F_k(DB, H, CA, N)$ an allometric equation linking above-ground biomass in d.m. ha^{-1} of shrubs to diameter at base (DB), shrub height (H), crown area/diameter (CA) and number of stems (N)

The methods presented under in the section III. 5(a.1.2) for the *ex-post* estimation of the carbon stocks in the shrub component can also be relevant for the *ex-ante* estimation purposes.

Step 2*:* Estimation of carbon stocks of herb biomass

Herbaceous vegetation usually represents a small proportion (1 to 3 %) of the above-ground biomass, hence its change over project lifetime is expected to be negligible. Under this methodology, the measurement of herb biomass is not mandatory for the *ex-ante* estimation provided herb biomass of the project scenario will increase or will at least remain the same as that of the herb biomass of baseline scenario. In situations where herb biomass is proposed to be estimated as part of the baseline study, the methods outlined under in the section III. 5(a.1.2) for the *ex-post* estimation of the carbon stocks of herb component can be considered for the *ex-ante* estimation.

a.2 Changes in Carbon Stock of Below-ground Biomass

$$\Delta C_{BB,ijk,t} = (C_{BB,ijk,t_2} - C_{BB,ijk,t_1}) / T_B \qquad \textbf{(B.28)}$$

$$C_{BB,ijk} = (C_{BB\_Tree,ijk} + C_{BB\_NTree\_Shrub,ijk} + C_{BB\_NTree\_Herb,ijk}) \qquad \textbf{(B.29)}$$

Or

$$\Delta C_{BB,ijk,t} = (\Delta C_{BB\_Tree,ijk,t} + \Delta C_{BB\_NTree\_Shrub,ijk,t} + \Delta C_{BB\_NTree\_Herb,ijk,t}) \qquad \textbf{(B.30)}$$

where:

$C_{BB,ijk,t2}$ carbon stock in belowground biomass for stratum *i* sub-stratum *j* species *k* calculated at time t_2 in t C

$C_{BB,ijk,t1}$, carbon stock in belowground biomass for stratum *i* sub-stratum *j* species *k* calculated at time t_1 in t C

$C_{BB\_Tree,ijk}$ carbon stock in belowground biomass of living trees for stratum *i* substratum *j* species *k* in t C

$C_{BB\_NTree\_Shrub,ijk}$ carbon stock in belowground biomass of non-tree shrubs for stratum *i* substratum *j* species *k* in t C

$C_{BB\_NTree\_Herb,ijk}$	carbon stock in belowground biomass of herb for stratum *i* substratum *j* species *k* in t C
T_B	number of years between measurement at time t_2 and t_1 for biomass
$\Delta C_{BB\_Tree,ijk,t}$	annual change in the belowground tree biomass in stratum *i* sub-stratum *j* species *k* at time *t* in t C
$\Delta C_{BB\_NTree\_Shrub,ijk,t}$	annual carbon stock change in the belowground non-tree shrub biomass in stratum *i* sub-stratum *j* species *k* at time *t* in t C yr^{-1}
$\Delta C_{BB\_NTree\_Herb,ijk,t}$	annual carbon stock change in the belowground herb biomass in stratum *i* sub-stratum *j* species *k* at time *t* in t C yr^{-1}

The below-ground biomass is represented as a proportion of the above-ground biomass. The changes in the below-ground biomass shall be estimated using one of the following steps.

Step 1: Appropriate root-shoot ratio that most closely reflects the growth characteristics of the species group should be assessed from the literature/local research/ecological studies of the region. If local root-shoot ratios are not available, the Annex 3.A1, Table 3A1.8 of GPG/LULUCF (IPCC 2003) on the root-shoot ratios for different species types and forest types can be consulted to select the representative root-shoot ratios in order to estimate the changes in the below-ground biomass.

Step 2: Estimation of changes in carbon stocks of below-ground biomass using empirical methods.

When volume increment data are available from the yield tables, the annual above-ground biomass increment should be converted into below-ground biomass increment using the following equation. The root-shoot ratio selected in step 1 can be applied to the estimate of below-ground tree biomass.

$$\Delta C_{BB\_Tree,ijk} = [I_{Tree,ijk} \cdot D_k \cdot BEF_{jk} \bullet R_{T,k} \bullet CF_k] \qquad \textbf{(B.31)}$$

where:

$\Delta C_{BB,ijk}$	average annual below-ground tree biomass increment of stratum *i* sub-stratum *j* species *k* in t $C.ha^{-1}$
$R_{T,k,}$	root-shoot ratio of tree species *k*, dimensionless

Considering the small proportion of herb biomass, the below ground biomass of herb biomass can be ignored for *ex-ante* estimation. Therefore, changes in the carbon stock of shrub biomass will only be relevant and can be estimated as the product of above-ground shrub biomass and root-shoot ratio of the shrub species. In the absence of local data on the shrub species, the data from Good Practice Guidance on LULUCF can be used to estimate the below ground shrub biomass.

$$\Delta C_{BB\_NTree\_Shrub,ijk} = \Delta C_{AB\_NTree\_Shrub,ijk} \bullet R_{S,k} \qquad \textbf{(B.32)}$$

where:

$R_{S,}$	root-shoot ratio of shrub species *k*, dimensionless

In the absence of location specific data on root-shoot ratios, ex-ante below-ground biomass could be estimated using published literature. For example, relationship between below-ground biomass to above-ground biomass (root-shoot ratio of ~ 0.2) (Cairns et al. 1997)[13] is based on large number of studies from several geographic regions.

$$B_{BB\,ijk} = \exp[-0.7747 + 0.8836 \bullet \ln B_{AB\,,ijk}] \qquad \textbf{(B.33)}$$

where:

$B_{BB\,,ijk}$	below-ground tree biomass of stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1}
$B_{AB\,,ijk}$	above-ground tree biomass of stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1}

a.3 Deadwood (C_{DW})

Dead wood is highly variable due to differences in the growth rates of species, mortality rates, past disturbance, decay rates, and management practices. As a stand grows, dead wood is expected to increase due to increase in mortality from factors such as competition, shading, and climate. Deadwood is either negligible at the early stages of the project, but would increase as the A/R areas age. The natural rates of mortality for each species and age class are likely to vary. For example, mortality rates in young stands are smaller than those for mature stands.

The changes in deadwood biomass shall be estimated using the following methods.

Step 1: Collect age-specific mortality rates of the species used in A/R activities. If local and national studies do not provide the natural rates of mortality, mortality factors from Good Practice Guidance on LULUCF shall be used.

Step 2: The decomposition rates of timber in a stand and can be estimated from the data of ecological studies in the region in which the project is located. It is recommended to use decomposition factors of the closely related species in situations where species-specific decomposition factors are not available.

Step 3: Estimation of carbon stock changes in deadwood using empirical methods can be done using mortality estimates and decomposition factors.

The average annual change in the deadwood biomass based on the natural rate of mortality is estimated as follows.

$$\Delta C_{DW\,ijk} = \Delta C_{AB\_Tree_{ijk}} \bullet M_k \bullet (1 - DC_k) \qquad \textbf{(B.34)}$$

where:

$\Delta C_{DW\,,ijk}$	average annual change in the carbon stock of dead wood in stratum *i* sub-stratum *j* species *k* in t C yr^{-1}
M_k	average annual rate of natural mortality for species *k,* dimensionless
DC_k	decomposition factor for species *k*, dimensionless

[13] Cairns, M.A.; Brown, S. et al. (1997): Root biomass allocation in the world's upland forests. *Oecologia* (1):1-11.

a. 4. Litter (C_L)

The dead wood with a diameter of less than 10 cm and other fallen material such as twigs, leaves and branches is categorized under litter. Considering the increases in the above-ground biomass and deadwood, litter component is expected to increase under the project scenario. However, seasonal factors, timber harvesting, site preparation, disturbance, and fire can influence the rate of litter accumulation. The project participants may chose to account or not account litter for the *ex-ante* estimation purposes.

If the project participants decide to measure and account the litter for the *ex-ante* purposes using empirical methods, the steps outlined for the *ex-post* estimation under section III.5 (a.4) as part of the monitoring methodology shall be followed.

a.5. Soil organic carbon (C_{SOC})

The soil organic carbon is expected to increase under the A/R activity in all categories of degraded lands due to a reduction in soil erosion, improvement in soil physical properties, and increases in dead wood and litter from increased canopy density. The measurable changes in soil organic carbon can be observed after 15-20 years of stand growth. The major variables that influence soil organic carbon include soil depth, bulk density, and concentration of organic carbon.

The changes in soil organic carbon can be assessed from empirical methods based on the research and published data by comparing the non-forested and forested lands in the project area or by conducting sample studies to estimate the soil organic matter in the project area as outlined below.

Available empirical data on soil carbon status from degraded lands and forested lands can be used in the *ex-ante* estimation of carbon stock changes under the project scenario. In this regard, data on soil carbon in forested and non-forested similar ecosystem needs to be compared as follows.

$$\Delta C_{SOC_{ijk}} = \left[(C_{SOC\_For_{ijk}} - C_{SOC\_Non\_For_i}) \bullet A_{ijk} \right] / T_{For,ijk} \qquad \textbf{(B.35)}$$

$$C_{SOC\_For_{ijk}} = C_{SOC\_REF_{ijk}} \bullet f_{ijk} \qquad \textbf{(B.36)}$$

where:

$\Delta C_{SOC,ijk}$	average annual carbon stock change in soil organic matter for stratum *i* sub-stratum *j* species *k* in t C. yr^{-1}
$C_{SOC\_For,ijk}$	soil organic carbon stock of afforested/reforested area or forested area that corresponds to the stratum i sub-stratum j species k in t C.ha^{-1}
$C_{SOC\_Non\_For,i}$	soil organic carbon stock of non-forested degraded lands that correspond to the stratum *i* sub-stratum *j* species *k* in t C.ha^{-1}
A_{ijk}	area of stratum *i* substratum *j* species *k* in ha
$T_{For,ijk}$	time period required for transition from $SOC_{Non\text{-}For,ij}$ to $SOC_{For,ijk}$ in years
$C_{SOC\_REF,ijk}$	reference soil organic carbon stock under the native unmanaged in t C.ha^{-1}. The SOC_{REF} refers to the stable soil organic carbon under native forests (Table 3.2.4 of Good Practice Guidance on LULUCF).
f_{ijk}	adjustment factor for the effect of management intensity, dimensionless. The value for adjustment factor is expected to range between 0-1. If specific value is not available, default value between 0.5 and 1.0 shall be chosen.

The values chosen for $SOC_{For,ijk}$, $SOC_{REF,ijk}$ and f_{ij} should be based on the species and management intensity that are applicable to the project context.

If no empirical data on the soil organic carbon status of non-forest lands is readily available, sampling methods can be used. The project participants will need to conduct field surveys using temporary sample plots to collect the data on initial carbon stocks of the project area.

The steps and procedures of sampling and estimation outlined in section III.5(a.5) for the *ex-post* estimation of soil organic carbon will be followed to estimate the stock of soil carbon in the project area prior to and during the project.

$$C_{SOC\_Non\_For,i} = CC_{SOCC\_Non\_For,i} \bullet BD_i \bullet D_i \bullet FC_i \bullet M \qquad \textbf{(B.37)}$$

where:

$C_{SOCC\_Non\_For,i}$	soil organic carbon content of non-forested degraded land that corresponds to stratum *i* species *k* as determined in laboratory in g C (100g soil)$^{-1}$
BD_i	bulk density (soil mass/volume of sample) of non-forested land that corresponds to stratum *i* as determined in laboratory in g.cm^{-3}
D_i	soil depth corresponding to stratum *i* in cm
$FC_{,kt}$	1 – (% volume of coarse fragments/100) to adjust the proportion of volume of sample occupied by coarse fragment of > 2mm of in stratum *i*, dimensionless
M	multiplier to convert units into t C ha^{-1}. Value depends on size of soil sample, dimensionless

(b) GHG emissions by sources

The project emissions result from the implementation of the A/R project. The likely sources of project emissions include: emissions from fossil fuels used in carrying out A/R activities such as site preparation, transport, and silvicultural operations; loss of non-tree biomass in the site preparation; biomass burn due to natural fires or from management related activities; and the application of nitrogenous fertilizers.

The increases in the GHG emissions due to implementation of the A/R CDM project activity should be estimated using the following relationship.

$$GHG_E = E_{FuelBurn} + E_{BiomassLoss} + E_{BiomassBurn} + E_{N2O\_direct\_N_{fertilizer}} \qquad \textbf{(B.38)}$$

where:

GHG_E	sum of increases in GHG emissions within the project boundary from the implementation of the proposed A/R CDM project activity in t CO_2e
$E_{FuelBurn}$	increase in GHG emissions from the burning of fossil fuels within the project boundary in t CO_2e
$E_{BiomassLoss}$	increase in GHG emissions from the loss of biomass in the site preparation within the project boundary in t CO_2

$E_{BiomassBurn}$ increase in GHG emissions from the biomass burning within the project boundary in t CO_2e

$E_{N_2O_{direct-N_{fertilizer}}}$ increase in N_2O emissions from the application of nitrogenous fertilizers within the project boundary in t CO_2e

b.1. CO_2 emissions from fossil fuels use in the project

Project emissions associated with the use of fossil fuels in A/R project activities such as site preparation, transportation, and silvicultural activities should be accounted along with the duration of these activities. For *ex-ante* estimation, fossil fuel consumption should be computed based on the fossil fuel use under standard operations procedures prescribed for the activities.

$$E_{FuelBurn} = (CSP_{diesel} \bullet EF_{diesel} + CSP_{gasoline} \bullet EF_{gasoline}) \bullet 0.001 \qquad \textbf{(B.39)}$$

where:

CSP_{diesel} quantity of diesel consumption in litre (l) yr^{-1}. Average annual diesel consumption estimated based on the fuel consumption data of standard operating procedures.

$CSP_{gasoline}$ quantity of gasoline consumption in the project in litre (l) yr^{-1}. Average annual gasoline consumption estimated based on the fuel consumption data of standard operating procedures.

EF_{diesel} emission factor for diesel in kg CO_2 $liter^{-1}$

$EF_{gasoline}$ emission factor for gasoline in kg CO_2 $liter^{-1}$

0.001 factor for conversion of kg to tonnes

b.2. Emissions from the decline in the carbon stock of non-tree vegetation

Some proportion of the pre-project non-tree vegetation is expected to disappear during the site preparation or due to competition from planted species. Some vegetation may re-grow even if all non-tree vegetation is removed during the site preparation. Therefore, the methods outlined here to account emissions from he decline of carbon of non-tree vegetation can be considered conservative. The following steps shall be followed in estimating the CO_2 emissions from the loss of carbon stock in the biomass of non-tree vegetation.

Step 1: Area associated with the loss of non-tree biomass should be estimated based on the area likely to be affected in site preparation and the spacing used in the A/R project activity.

Step 2: The amount of carbon stock of non-tree biomass lost from the area affected in site preparation shall be calculated based on the area likely to be affected and the biomass associated with the area.

$$E_{BiomassLoss_{s,i}} = \sum_i A_{NT\_BiomassLoss_{s,i}} \bullet B_{AB\_NTree_i} \bullet CF_{NTree} \bullet 44/12 \qquad \forall\, t = 1 \quad \textbf{(B.40)}$$

$$E_{BiomassLoss_{s,t}} = 0 \qquad \forall\, t > 1$$

where:

$A_{NT\_Biomass\_Loss,i}$	area of stratum i in ha
$B_{AB\_NTtree,i}$	average biomass stock of non-tree vegetation on land to be planted before the start of a proposed A/R CDM project activity for stratum i in t.d.m. ha^{-1}
CF_{NTree}	carbon fraction of dry biomass in non-tree vegetation in t C $(t.d.m)^{-1}$
44/12	ratio of molecular weights of CO_2 and carbon, dimensionless

b.3 Greenhouse gas emissions from biomass burn

The ex-ante estimation of fire risk can be assessed from the historic data on fire occurrence in the region. Alternatively data on fire occurrences reported in local studies or published literature or expert opinion on the area subject to fire risk shall be taken into account in assessing the area subject to the risk of fires.

Emissions from fire under this methodology include CO_2 and as well as CH_4 and N_2O. The non-CO_2 GHG emissions result from the incomplete combustion of biomass. The parameters on GHG emissions from biomass burning should be assessed from the local research studies or Good Practice Guidance on LULUCF or revised IPCC 1996 Guidelines for LULUCF. The steps to be followed in assessing the GHG emissions from biomass burn include:

Step 1: The area subjected to biomass burn from the natural or anthropogenic influences shall be assessed.

Step 2: The amount of non-CO_2 emissions is dependent on the loss of carbon in the biomass burn. Therefore, CO_2 emissions from biomass burn should be estimated prior to the estimation of non-CO_2 emissions.

$$E_{BiomassBurn,CO_2} = A_{BiomassBurn,i} \bullet B_{AB\_NTree,i} \bullet CE \bullet CF_{NTree} \bullet 44/12 \qquad \textbf{(B.41)}$$

where:

$A_{BiomassBurn,i}$	area of biomass burn in stratum i in ha yr^{-1}
$B_{AB\_NTree,i}$	average stock in aboveground biomass for stratum i prior to burn in t.d.m. ha^{-1}
CE	combustion efficiency, dimensionless, (IPCC default =0.5)
CF_{NTree}	carbon fraction of dry biomass in t C $(t.d.m.)^{-1}$

Step 3: Suitable combustion efficiencies (refer to Tables 3A.1.12, 3A.1.14 GPG/LULUCF) and emission factors (Tables 3.A 15 and 3.A.16 of Good Practice Guidance on LULUCF) should be chosen to estimate the emissions of non-CO_2 gases. If national data are not available, mean emission factors for biomass burn that release CH_4 (0.012) and N_2O (0.007) shall be used.

The *methane (CH_4)* emissions from biomass burn[14]:

$$E_{BiomassBurn,CH_4} = E_{BiomassBurn,CO_2} \bullet GWP_{CH4} \bullet EF_{CH4} \bullet 12/44 \bullet 16/12 \qquad \textbf{(B.42)}$$

[14] As per Table 5.7,1996 Revised IPCC Guideline for LULUCF and Equation 3.2.19 of GPG LULUCF

where:

$E_{BiomassBurn,CH4}$	CH_4 emission from biomass burning in slashes and burn in t CO_2-eq yr^{-1}
GWP_{CH4}	global warming potential for CH_4 (IPCC default = 21)
$12/44$	ratio of molecular weights of carbon and CO_2, dimensionless
$16/12$	ratio of molecular weights of CH_4 and carbon, dimensionless
EF_{CH4}	emission factor for CH_4 t CH_4 $(t\ C)^{-1}$ (IPCC default for CH_4 = 0.012)

The *nitrous oxide (N_2O)* emissions from biomass burn:

$$E_{BiomassBurn,N_2O} = E_{BiomassBurn,CO_2} \bullet GWP_{N_20} \bullet (C/N\ ratio) \bullet EF_{N_20} \bullet 44/28 \bullet 12/44 \qquad \textbf{(B.43)}$$

where:

$E_{BiomassBurn,N2O}$	N_2O emission from biomass burning in slash and burn in tCO2-eq yr^{-1}
GWP_{N_2O}	global warming potential for N_2O (IPCC default for N_2O = 310)
$C/N\ Ratio$	carbon-nitrogen ratio, dimensionless
$12/44$	ratio of molecular weights of Carbon and CO_2, dimensionless
$44/28$	ratio of molecular weights of N_2O and nitrogen, dimensionless
EF_{N_2O}	emission ratio for N_2O (IPCC default factor = 0.0007)

Step 4: Sum of non-CO_2 emissions from biomass burning.

$$E_{Non-CO2\_BiomassBurn} = E_{BiomassBurn,N2O} + E_{BiomassBurn,\ CH4} \qquad \textbf{(B.44)}$$

where:

$E_{Non-CO2,\ BiomassBurn}$	increase in non-CO_2 emission from biomass burning in t CO_2eq yr^{-1}

b.3. Estimation of nitrous oxide emissions from fertilization[15]

In situations where fertilizer is used in the project area, the emissions from N_2O should be calculated as per the steps outlined below.

Step 1: Estimate the amount of synthetic and organic fertilizer applied in the project area

$$F_{SN} = N_{SN-Fert} \bullet (1 - Frac_{GASF}) \qquad \textbf{(B.45)}$$

$$F_{ON} = N_{ON-Fert} \bullet (1 - Frac_{GASM}) \qquad \textbf{(B.46)}$$

15 Based on Equation 3.2.18 of IPCC GPG-LULUCF

where:

F_{SN}	amount of synthetic fertilizer nitrogen applied adjusted for volatilization as NH_3 and NO_X in t N yr^{-1}
F_{ON}	amount of organic fertilizer nitrogen applied adjusted for volatilization as NH_3 and NO_X in t N yr^{-1}
$N_{SN-Fert}$	amount of synthetic fertilizer nitrogen applied in t N yr^{-1}
N_{ON_Fert}	amount of organic fertilizer nitrogen applied in t N yr^{-1}
$Frac_{GASF}$	fraction that volatilises as NH_3 and NO_X for synthetic fertilizers, dimensionless
$Frac_{FASM}$	fraction that volatilises as NH_3 and NO_X for organic manure, dimensionless

When country-specific N_2O emission factors are not available, default emission factor EF_1 of 1.25 % for N applied should be used. As per 1996 IPCC Guidelines, the default values for the fractions of synthetic fertilizer and organic manure emitted as NO_X and NH3 - 0.1 and 0.2 respectively. Project developers should develop emission factors that are relevant for their project.

Step 2*:* Calculate nitrous oxide emissions from synthetic and organic fertilizers

$$N_2O_{direct-N_{fertilizer}} = \left[(F_{SN_t} + F_{ON_t}) \cdot EF_1\right] \bullet GWP_{N_2O} \bullet 44/28 \qquad \textbf{(B.47)}$$

$N_2O_{direct-N_{fertilizer}}$	direct N_2O emissions as a result of nitrogen application within the project boundary in t CO_2-eq yr^{-1}
EF_1	emission factor for emissions from N inputs in t N_2O-N (t N input)$^{-1}$
GWP_{N_2O}	global warming potential for N_2O (IPCC default = 310)
$44/28$	ratio of molecular weights of N_2O and nitrogen, dimensionless

(c) Actual net GHG removals by sinks

$$\Delta C_{ACTUAL} = \sum_{i=1} \sum_{j=1} \sum_{k=1} \left[\Delta C_{ijk} - GHG_E\right] \qquad \textbf{(B.48)}$$

where:

ΔC_{ACTUAL}	actual net greenhouse gas removals by sinks in t CO_2-eq yr^{-1}
ΔC_{ijk}	average annual carbon stock change in living biomass of trees for stratum i sub-stratum *j* species *k* in t CO_2 yr^{-1}.
GHG_E	GHG emissions by sources within the project boundary as a result of the implementation of an A/R CDM project activity in t CO_2-eq yr^{-1}

8. Leakage

In choosing parameters and making assumptions, the project participants should retain conservative approach, i.e. if different values for a parameter are plausible, a value that does not lead to an underestimation of leakage emissions should be applied.

According to the applicability conditions for this methodology, the degraded land proposed for A/R CDM project activity continues to provide at least the same amount of goods and services. Consequently, as a result of the A/R CDM project activity, agricultural or pastoral activities will not be displaced from the project sites to other locations.

Similarly, the A/R CDM project activity will not result in a reduction of reforestation activities or increase the deforestation activities outside of the project boundary.

The only potential leakage source that should be considered by project participants are CO_2 emissions associated with the fossil fuel combustion in the vehicles used for the transportation of seedling, labour, staff and harvest products to or from project sites (while avoiding double-counting). The CO_2 emissions can be estimated based on the fuel consumption of the vehicles and a CO_2 emission factor, as follows:

$$LK_{Vehicle} = \sum_{v}\sum_{f}(EF_{vf} \cdot FuelConsumption_{vf}) \quad \textbf{(B.49)}$$

$$FuelConsumption_{vf} = n_{vf} \cdot k_{vf} \cdot e_{vf} \quad \textbf{(B.50)}$$

$LK_{Vehicle}$	CO_2 emissions from fossil fuel combustion in vehicular transportation in t CO_2eq yr^{-1}
v	vehicle type
f	fuel type
EF_{vf}	CO_2 emission factor for vehicle type v with fuel type f, dimensionless
$FuelConsumtpion_{vf}$	consumption of fuel type f of vehicle type v in litres
n_{vf}	number of vehicles
k_{vf}	kilometres travelled by vehicle type v with fuel type f at time t in km
e_{vf}	fuel efficiency of vehicle type v with fuel type f in litres km^{-1}

If national emission factors are available, they shall be used. In the absence of local data or national emission factors, the default emission factors presented in the Revised 1996 IPCC Guidelines and updated in the GPG 2000 shall be used.

The equation used for the estimation of the leakage is same under the *ex-ante* and *ex-post* estimation methods. In the case of the *ex-ante* estimation of leakage, the expected values of fossil fuel use and distance travelled shall be used. In the case of *ex-post* estimation, monitored data on the transportation is used.

9. Ex ante net anthropogenic GHG removal by sinks

The net anthropogenic GHG removals by sinks represent the difference of actual net GHG removal by sinks and the net baseline net GHG removal by sinks, and the leakage from the project.

$$C_{AR-CDM} = \Delta C_{ACTUAL} - \Delta C_{BSL} - LK_{vehicle} \tag{B.51}$$

where:

C_{AR-CDM} net anthropogenic greenhouse gas removals by sinks in t CO_2eq yr^{-1}

ΔC_{ACTUAL} actual net greenhouse gas removals by sinks in t CO_2eq yr^{-1}

ΔC_{BSL} baseline net greenhouse gas removals by sinks in t CO_2-eq yr^{-1}

$LK_{vehicle}$ leakage in t CO_2-eq yr^{-1}

10. Uncertainties

The methodology ensures that the net anthropogenic GHG removals by sinks are estimated under the project in a conservative manner taking into account the uncertainties associated with the secondary data.

The methods and approaches used to quantify uncertainties are the same under the *ex-ante* and *ex-post* estimation methods. Therefore, the methods presented in section III.11 for quantifying the uncertainty in the *ex-post* estimation of the actual net GHG removals by sinks shall be relevant for the assessment of uncertainty in the *ex-ante* estimates of actual net GHG removals by sinks outlined in this section.

11. Data needed for ex-ante estimations

Data/ Parameters	Descriptions	Vintage	Resolu-tion	Sources
UNFCCC decisions	Project eligibility	1997 up to recent	Global/ national	UNFCCC/ International
Land use / cover data	To determining the baseline approach To demonstrate the eligibility of land	Early to recent	ha	Local
Land use / cover map	To demonstrate the eligibility of land; stratification of project area	~ 1990 & recent	ha	Regional Local
Physiography map	Stratification of project area	Current/ recent	ha/ sq.km	Map
Soil map	Stratification of project area	Current/ recent	ha /sq.km	Map
Satellite image	To demonstrate the eligibility of land; stratification of project area	~1990 & recent	ha	Local
National policies	Additionality consideration	Current/ recent	National/ local	National /sector
Fixed costs	land rent, buildings, machinery, site preparation, nursery, supervision, training, consultation, repairs, fire control etc. that occur in the establishment period	Current/ recent	Local	Local data
Variable costs	costs of planting, weeding, pesticides, fertilization, thinning, harvesting, fuel, transportation, and disease control, patrolling, administration, etc.	Current/ recent	Local	Local data
Regulatory costs	costs of project preparation, validation, registration, monitoring, etc.	Current/ recent	Local	Local/National data
Revenue	Timber, fuelwood, non-wood products, sale of CERs, & revenue etc.	Current/ recent	Local	Local data

Investment analysis	IRR, NPV, B:C ratio	Current/ recent	Local	Local
i	stratum of the baseline 1,2,3…i	Current	Local	Survey
j	substratum of the baseline 1,2,3…j	Current	Local	Local
k	species of the baseline 1,2,3,...k	Current	Local	Local
t	1 to length of crediting period	Current	Local	UNFCCC
$\Delta C_{BDL\_ijk,t}$	average annual change in the carbon stocks of bare lands or degraded lands with sparse pre-existing vegetation in stratum *i* substratum *j* species *k* in t CO_2 yr^{-1} (set to zero)	Current	Local	Local data/ estimate
$\Delta C_{BDL\_LB_{ijk,t}}$	sum of annual changes in the carbon stocks of living biomass (above- and below-ground) in stratum *i* substratum *j* species *k* in t CO_2 yr^{-1}	Most recent	Local	Local data/ estimate
$\Delta C_{BAR,ijk,t}$	average annual change in the carbon stocks of pre-project A/R attributable to stratum *i* sub-stratum *j* species *k* in t CO_2 yr^{-1}	Most recent	Local	Local data/ estimate
$\Delta C_{BAR\_LB\_Tree_{ijk,t}}$	average annual change in the carbon stocks of living tree biomass pools (above-ground and below-ground tree biomass) of the pre-project A/R attributable to stratum *i* sub-stratum *j* species *k* in t CO_2 yr^{-1}	Most recent	Local	Local data/ estimate
$\Delta C_{BAR\_S_{ijk,t}}$	average annual change in the carbon stocks of soil pool of the pre-project A/R attributable to stratum *i* sub-stratum *j* species *k* in t CO_2 yr^{-1}	Most recent	Local	Local data/ estimate
$\Delta C_{BSL,t}$	baseline net GHG removals by sinks in year *t* in t CO_2eq yr^{-1}	Most recent	Local	Local data / estimate
$\Delta C_{ijk,t}$	average annual change in carbon stock in stratum *i* sub-stratum *j* species *k* in t CO_2eq yr^{-1}	Most recent	Local	Local data / estimate
$\Delta C_{G,ijk,t}$	average annual growth in carbon *stock* for stratum *i* sub-stratum *j* species *k* in t CO_2eq yr^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$\Delta C_{L,ijk,t}$	average annual loss in carbon *stock* for stratum *i* sub-stratum *j* species *k* in t CO_2eq yr^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
A_{ijk}	area of stratum *i* sub-stratum *j* species *k* in ha	Current	Local	Local data/ survey
$\Delta G_{Mean\_LB\_Tree}$	average annual increment of total dry biomass of living trees for stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1} yr^{-1}	Most recent	Local / Global default	Local data / estimate
CF_k	carbon fraction of the biomass for species k in t C $(t.d.m.)^{-1}$	Most recent	Local / Global default	Local/National/ GPG-LULUCF
44/12	ratio of molecular weights of CO_2 and carbon, dimensionless			
$G_{w,ijk}$	average annual aboveground dry biomass increment of living trees for stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1} yr^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
R_{jk}	root-shoot ratio for species *k* age class *j,* dimensionless. The root-shoot ratio may change as a function of the above-ground biomass present in year *t*	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$I_{v,ijk}$	average annual increment in merchantable volume for stratum *i* sub-stratum *j* species *k* in m^3 ha^{-1} yr^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
D_k	basic wood density for species *k* in t.d.m. m^{-3}	Most recent	Local / Global default	Local/National/ GPG-LULUCF

$BEF_{1,jk}$	biomass expansion factor for conversion of annual net increment (including bark) in the merchantable volume to total aboveground biomass increment for species *k* age class *j*, dimensionless	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$\Delta C_{LB,ijk}$	average annual change in the carbon stocks of biomass for stratum *i* sub-stratum *j* species *k* in t C yr^{-1}	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{2,LB,ijk}$	carbon stock in the biomass of stratum *i* sub-stratum *j* species *k* calculated at measurement time period 2 in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{1,LB,ijk}$	carbon stock in the biomass of stratum *i* sub-stratum *j* species *k*, calculated at measurement time period 1 in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
T_B	interval in years between measurement periods 2 and 1 to assess the biomass change			
$C_{2,LB\_Tree,ijk}$	total carbon stock in living biomass of trees for stratum *i* sub-stratum *j* species *k* calculated at time 2 in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{1,LB\_Tree,ijk}$	total carbon stock in living biomass of trees for stratum *i* sub-stratum *j* species *k* calculated at time 1 in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{AB\_Tree,ijk}$	carbon stock in aboveground tree biomass for stratum *i* sub-stratum *j* species *k* in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{BB\_Tree,ijk}$	carbon stock in belowground tree biomass for stratum *i* sub-stratum *j* species *k* in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
V_{ijk}	merchantable volume of stratum i sub-stratum j species k in m^3 ha^{-1}	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$BEF_{2,jk}$	biomass expansion factor for conversion of merchantable volume to above-ground tree biomass for age class *j* species *k*, dimensionless	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$f(DBH,H)$	allometric equation quantifying the relationship between above-ground biomass to the diameter at breast height (DBH) and tree height (H) of tree species *k* in kg $tree^{-1}$	Most recent	Local / Global default	Local/National/ GPG-LULUCF
nTR_{ik}	number of trees in stratum *i* species *k* in trees ha^{-1}	Most recent	Local	Local
$\Delta C_{SOC,ijk}$	carbon stock in the soil for stratum *i* sub-stratum *j* under species *k* calculated at time 2 in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{SOC\ 2,ijk}$	annual average change in the carbon stock of soil pool of stratum *i* sub-stratum *j* species *k* in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{SOC\ 1,ijk}$	carbon stock in the soil for stratum *i* sub-stratum *j* under species *k* calculated at time 1 in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
T_S	interval in years between period 2 and 1 to assess the change in soil organic carbon			
$\Delta C_{ijk,t}$	average annual change in carbon stock in the pools for stratum *i* sub-stratum *j* species *k* in t CO_2 yr^{-1} in year t	Most recent	Stratum/ species	Calculated
$\Delta C_{AB,ijk,t}$	average annual change in carbon stock in aboveground biomass for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year t	Most recent	Stratum/ species	Calculated
$\Delta C_{BB,ijk,t}$	average annual change in carbon stock in belowground biomass for stratum *i* sub- stratum *j* species *k* in t C yr^{-1} in year t	Most recent	Stratum/ species	Calculated

$\Delta C_{DW,ijk,t}$	average annual change in carbon stock in deadwood for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year t	Most recent	Stratum/ species	Calculated
$\Delta C_{L,ijk,t}$	average annual change in carbon stock in litter for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year t	Most recent	Stratum/ species	Calculated
$\Delta C_{SOC,ijk,t}$	average annual change in carbon stock in soil organic matter for stratum *i* substratum *j* species *k* in t C yr^{-1} in year t	Most recent	Stratum/ species	Calculated
$C_{AB,ijk,t2}$	carbon stock in aboveground biomass for stratum *i* sub-stratum *j* species *k* calculated at time t_2 in t C	Most recent	Stratum/ species	Calculated
$C_{AB,ijk,t1}$	carbon stock in aboveground biomass for stratum *i* sub-stratum j species *k* calculated at time t_1 in t C	Most recent	Stratum/ species	Calculated
$C_{AB\_Tree,ijk}$	carbon stock in aboveground biomass of living trees for stratum *i* substratum *j* species *k* in t C	Most recent	Stratum/ species	Calculated
$C_{AB\_NTree,ijk}$	carbon stock in aboveground biomass of non-tree vegetation for stratum *i* substratum *j* species *k* in t C	Most recent	Stratum/ species	Calculated
$\Delta C_{AB\_Tree,ijk,t}$	average annual change in the above-ground tree biomass in stratum *i*, sub-stratum *j* species *k* at year t in t C	Most recent	Stratum/ species	Calculated
$\Delta C_{AB\_NTree,ijk}$	average annual change in the above-ground non-tree biomass in stratum *i*, sub-stratum *j* species *k* at year t in t C	Most recent	Stratum/ species	Calculated
$\Delta C_{AB\_Tree,ijk}$	average annual above-ground tree biomass increment for stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1} yr^{-1}	Most recent	Stratum/ species	Calculated
$G_{AB\_Stem,ijk}$	stem biomass increment in stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1}	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$G_{AB\_Branch,ijk}$	foliage biomass increment ($G_{AB\_Stem,\ ijk}$ * Ff) in stratum i sub-stratum j species *k in* t.d.m. ha^{-1}	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$G_{AB\_Foliage,ijk}$	branch biomass increment ($G_{AB\_Stem,\ ijk}$* Fb) in stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1}	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
CF_k	carbon fraction for species k, dimensionless	Most recent	Species	Local/National/ GPG-LULUCF
$\Delta C_{AB\_Tree,ijk}$	annual change in the above-ground tree biomass in stratum *i* sub-stratum *j* species *k* in t C	Most recent	Stratum/ species	Calculated
$\Delta C_{AB\_Tree\_Gro}$	annual growth in tree biomass in stratum *i* sub-stratum *j* species *k* t C. ha^{-1}	Most recent	Stratum/ species	Calculated
$\Delta C_{AB\_Tree\_Los}$	annual loss in tree biomass in stratum *i*, sub-stratum j species *k* in t C. ha^{-1}	Most recent	Stratum/ species	Calculated
$\Delta C_{AB\_Tree\_Har}$	annual change in the loss of tree biomass from harvest in stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1} yr^{-1}	Most recent	Stratum/ species	Calculated
$\Delta C_{AB\_Tree\_Dis}$	annual change in the loss of tree biomass from disturbance in stratum *i* sub-stratum *j* species k in t.d.m. ha^{-1} yr^{-1}	Most recent	Stratum/ species	Calculated
$f_j(DBH,H)$	allometric equation quantifying the relationship between above-ground biomass (d.m. ha^{-1}) to the mean diameter at breast height (DBH) and mean tree height (H) for species k; dimensionless.	Most recent	Local / Global default	Local/National/ GPG-LULUCF

$DBH(t), H(t)$	Growth/yield table that represents merchantable volume as a function of tree age.	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$\Delta C_{AB\_Tree,\ ijk}$	average annual above-ground tree biomass increment for stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1} yr^{-1}	Most recent	Stratum/ species	Calculated
$I_{Tree,ijk}$	average annual increment of merchantable timber volume for stratum *i* sub-stratum *j* species *k* in m^3 ha^{-1} yr^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$C_{AB\_NTree\_Shru}$	carbon stock in aboveground biomass of shrub for stratum *i* substratum *j* species *k* in t C	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$C_{AB\_NTree\_Herb}$	carbon stock in aboveground herb biomass for stratum *i* substratum *j* species *k* in t C	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$B_{AB\_NTree\_Shrub,ijk}$	above-ground non-tree shrub biomass of woody perennials in stratum *i* sub-stratum *j* (age class of tree) species *k* in t.d.m. ha^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
D^2_{ijk}	sum of all diameters squared for the woody perennial in stratum *i* sub-stratum *j* (age class of tree) species k in cm	Most recent	Local / Global default	Local/National/ GPG-LULUCF
H_i	height of the woody perennial from base to its tip in stratum *i* sub-stratum *j* (age class of tree) species *k* in m	Most recent	Local / Global default	Local/National/ GPG-LULUCF
CF_s	carbon fraction for shrub in t C $(t.d.m.)^{-1}$	Most recent	Local / Global default	Local/National/ GPG-LULUCF
A_Shrub,ijk	area of stratum *i* substratum *j* and shrub species *k* in ha	Most recent	Stratum/ species	Local data/ survey
$f_k(DB, H, C, N)$	allometric equation linking above-ground biomass in d.m. ha^{-1} of shrubs to diameter at base (DB), shrub height (H), crown area/diameter (CA) and number of stems (N)	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$C_{BB,ijk,t2}$	carbon stock in belowground biomass for stratum *i* sub-stratum *j* species *k* calculated at time t_2 in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{BB,ijk,t1}$	carbon stock in belowground biomass for stratum i sub-stratum j species *k* calculated at time t_1 in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{BB\_Tree,ijk}$	carbon stock in belowground biomass of living trees for stratum *i* substratum *j* species k in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{AB\_NTree\_Shrub,ijk}$	carbon stock in belowground biomass of non-tree shrubs for stratum *i* substratum *j* species *k* in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$C_{BB\_NTree\_Herb,ijk}$	carbon stock in belowground biomass of herb for stratum *i* substratum *j* species *k* in t C	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$\Delta C_{BB\_Tree,ijk,t}$	annual change in the belowground tree biomass in stratum *i* sub-stratum *j* species *k* at time t in t C	Most recent	Stratum/ species	Calculated
$\Delta C_{BB\_NTree\_Shrub,}$	annual carbon stock change in the belowground non-tree shrub biomass in stratum *i* sub-stratum *j* species *k* at time t in t C yr^{-1}	Most recent	Stratum/ species	Calculated
$\Delta C_{BB\_NTree\_Herb,ij}$	annual carbon stock change in the belowground herb biomass in stratum *i* sub-stratum *j* species *k* at time t in t C yr^{-1}	Most recent	Stratum/ species	Calculated
$\Delta C_{BB,ijk}$	average annual below-ground tree biomass increment of stratum *i* sub-stratum *j* species *k* in t C.ha^{-1}			
$R_{T,k,}$	root-shoot ratio of tree species *k*, dimensionless			

$C_{BB,ijk}$	below-ground biomass of stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1}			
$C_{AB\_Stem,ijk}$	carbon stock of stem biomass of stratum *i* sub-stratum *j* species *k* in t C ha^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$R_{T,k,F}$	root biomass as fraction of stem biomass for species *k*, dimensionless	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$R_{S,}$	root-shoot ratio of shrub species *k*, dimensionless			
$B_{BB,ijk}$	below-ground tree biomass of stratum i sub-stratum j species k (t.d.m. ha^{-1})	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$B_{AB,ijk}$	above-ground tree biomass of stratum i sub-stratum j species k (t.d.m. ha^{-1})	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$\Delta C_{DW,ijk}$	average annual change in the carbon stock of dead wood in stratum *i* sub-stratum *j* species *k* in t C yr^{-1}	Most recent	Stratum/ species	Calculated
M_k	average annual rate of natural mortality for species *k,* dimensionless	Most recent	Local / Global default	Local/National/ GPG-LULUCF
DC_k	decomposition factor for species *k*, dimensionless	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$\Delta C_{SOC,ijk}$	average annual carbon stock change in soil organic matter for stratum *i* sub-stratum *j* species *k* in t C. yr^{-1}	Most recent	Stratum/ species	Calculated
$C_{SOC\_For,ijk}$	soil organic carbon stock of afforested/reforested area or forested area that corresponds to the stratum i sub-stratum j species k in t $C.ha^{-1}$	Most recent	Stratum/ species	Calculated
$C_{SOC\_Non\_For,i}$	soil organic carbon stock of non-forested degraded lands that correspond to the stratum *i* sub-stratum *j* species *k* in t $C.ha^{-1}$	Most recent	Stratum/ species	Calculated
$T_{For,ijk}$	time period required for transition from $SOC_{Non-For,ij}$ to $SOC_{For,ijk}$ in years	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$C_{SOC\_REF,ijk}$	reference soil organic carbon stock under the native unmanaged in t C ha^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
f_{ijk}	adjustment factor for the effect of management intensity, dimensionless	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$C_{SOCC\_Non\_For,i}$	soil organic carbon content of non-forested degraded land that corresponds to stratum i species k as determined in laboratory in g C	Most recent	Stratum/ species	Calculated
BD_i	bulk density (soil mass/volume of sample) of non-forested land that corresponds to stratum *i* as determined in laboratory in $g.cm^{-3}$	Most recent	Local / Global default	Local/National/ GPG-LULUCF
D_i	soil depth corresponding to stratum *i* in cm	Most recent	Stratum/ species	Local data/ survey
$FC_{,kt}$	1 – (% volume of coarse fragments/100) to adjust the proportion of volume of sample occupied by coarse fragment of > 2mm of in stratum *i*, dimensionless	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
M	multiplier to convert units into t C ha^{-1}			

GHG_E	sum of increases in GHG emissions within the project boundary from the implementation of the proposed A/R CDM project activity in t CO_2e	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$E_{FuelBurn}$	increase in GHG emissions from the burning of fossil fuels within the project boundary in t CO_2e	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$E_{BiomassLoss}$	increase in GHG emissions from the loss of biomass in the site preparation within the project boundary in t CO_2	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$E_{BiomassBurn}$	increase in GHG emissions from the biomass burning within the project boundary in t CO_2e	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$E_{N_2O direct-N_{fertilizer}}$	increase in N_2O emissions from the application of nitrogenous fertilizers within the project boundary in t CO_2e	Most recent	Local / Global default	Local/National/ GPG-LULUCF
CSP_{diesel}	quantity of diesel consumption in litre (l) yr^{-1}	Most recent	Local	Local/National/ GPG-LULUCF
$CSP_{gasoline}$	quantity of gasoline consumption in the project in litre (l) yr^{-1}	Most recent	Local	Local/National/ GPG-LULUCF
EF_{diesel}	emission factor for diesel in kg CO_2 $liter^{-1}$	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$EF_{gasoline}$	emission factor for gasoline in kg CO_2 $liter^{-1}$	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$A_{NT\_Biomass\_Los}$	area of stratum *i* in ha	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$B_{AB\_NTree,i}$	average biomass stock of non-tree vegetation on land to be planted before the start of a proposed A/R CDM project activity for stratum *i* in t.d.m. ha^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
CF_{NTree}	carbon fraction of dry biomass in non-tree vegetation in t C $(t.d.m.)^{-1}$	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$A_{BiomassBurn,i}$	area of biomass burn in stratum *i* in ha yr^{-1}	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
$B_{AB,i}$	average stock in aboveground biomass for stratum *i* prior to burn in t.d.m. ha	Most recent	Stratum/ species	Local/National/ GPG-LULUCF
CE	combustion efficiency, dimensionless, (IPCC default =0.5)	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$E_{BiomassBurn,CH4}$	CH_4 emission from biomass burning in slashes and burn in t CO_2-eq yr^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
GWP_{CH4}	global warming potential for CH_4	Most recent	Global default	IPCC
EF_{CH4}	emission factor for CH_4 t CH_4 $(t\ C)^{-1}$ (IPCC default for CH_4 = 0.012)	Most recent	Global default	IPCC
$12/44$	ratio of molecular weights of carbon and CO_2; dimensionless		Global default	IPCC
$16/12$	ratio of molecular weights of CH_4 and carbon; dimensionless		Global default	IPCC

$E_{BiomassBurn,N2O}$	N_2O emission from biomass burning in slash and burn in tCO2-eq yr^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
GWP_{N_2O}	global warming potential for N_2O (IPCC default for N_2O = 310)	Most recent	Global default	IPCC
$C/N\ Ratio$	carbon-nitrogen ratio, dimensionless	Most recent	Global default	IPCC
$44/28$	ratio of molecular weights of N_2O and nitrogen, dimensionless		Global default	IPCC
EF_{N_2O}	emission ratio for N_2O (IPCC default factor = 0.0007)	Most recent	Global default	IPCC
$E_{Non-CO2,\ BiomassBurn}$	increase in non-CO_2 emission from biomass burning in t CO2eq yr^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
F_{SN}	amount of synthetic fertilizer nitrogen applied adjusted for volatilization as NH_3 and NO_X in t N yr^{-1}	Most recent	Local	Local/National/ GPG-LULUCF
F_{ON}	amount of organic fertilizer nitrogen applied adjusted for volatilization as NH_3 and NO_X in t N yr^{-1}	Most recent	Local	Local/National/ GPG-LULUCF
$N_{SN-Fert}$	amount of synthetic fertilizer nitrogen applied in t N yr^{-1}	Most recent	Local	Local/National/ GPG-LULUCF
N_{ON_Fert}	amount of organic fertilizer nitrogen applied in t N yr^{-1}	Most recent	Local	Local/National/ GPG-LULUCF
$Frac_{GASF}$	fraction that volatilises as NH_3 and NO_X for synthetic fertilizers, dimensionless	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$Frac_{FASM}$	fraction that volatilises as NH_3 and NO_X for organic manure, dimensionless	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$N_2O_{direct-N_{fertilizer}}$	direct N_2O emissions as a result of nitrogen application within the project boundary in t CO_2-eq yr^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
EF_1	emission factor for emissions from N inputs in t N_2O-N (t N input)-1	Most recent	Local / Global default	Local/National/ GPG-LULUCF
ΔC_{ACTUAL}	actual net greenhouse gas removals by sinks in t CO_2-eq yr^{-1}	Most recent	Project specific	Calculated
ΔC_{ijk}	average annual carbon stock change in living biomass of trees for stratum i sub-stratum j species k in t CO_2 yr^{-1}	Most recent	Project specific	Calculated
GHG_E	GHG emissions by sources within the project boundary as a result of the implementation of an A/R CDM project activity in t CO_2-eq yr^{-1}	Most recent	Project specific	Calculated
$LK_{Vehicle}$	CO_2 emissions from fossil fuel combustion in vehicular transportation in t CO_2eq yr^{-1}	Most recent	Project specific	Estimated
v	vehicle type	Most recent	Project specific	Local data
f	fuel type	Most recent	Project specific	Local data
EF_{vf}	CO_2 emission factor for vehicle type v with fuel type f, dimensionless	Most recent	Local / Global default	Local/National/ GPG-LULUCF
$FuelConssumption_{,vf}$	consumption of fuel type f of vehicle type v in litres	Most recent	Project specific	Estimated

n_{vf}	number of vehicles	Most recent	Project specific	Local data
k_{vf}	kilometres travelled by vehicle type *v i* with fuel type *f* at time *t* in km	Most recent	Project spcecifc	Estimated
e_{vf}	fuel efficiency of vehicle type *v* with fuel type *f* in litres km^{-1}	Most recent	Local / Global default	Local/National/ GPG-LULUCF
C_{AR-CDM}	net anthropogenic greenhouse gas removals by sinks in t CO_2eq yr^{-1}	Current	Project specific	Calculated
ΔC_{ACTUAL}	actual net greenhouse gas removals by sinks in t CO_2eq yr^{-1}	Current	Project specific	Calculated
ΔC_{BSL}	baseline net greenhouse gas removals by sinks in t CO_2-eq yr^{-1}	Current	Project specific	Calculated
LK	leakage in t CO_2-eq yr^{-1}	Current	Project specific	Calculated

12. Other information

(a) Calculation of tCERs and lCERs

The baseline net GHG removals by sinks, actual net GHG removals by sinks and net anthropogenic GHG removals by sinks are expressed annually. Some sources such as fertilizer application, machinery usage and slash and burn occur only in selected years. The CERs will not be issued annually, but at each verification interval. The formulae for calculating tCERs or lCERs outlined in section III. 9 represent the CERs issued for the period corresponding to the verification interval.

Section III: Monitoring methodology description

1. Monitoring project boundary and project implementation

The monitoring of project implementation involves several tasks such as monitoring of the project initiation, monitoring of the area afforested or reforested under the project, monitoring of the forest establishment, and monitoring of the forest management activities. It also includes the adoption of a monitoring frequency over which carbon pools of the project are monitored, data are collected and changes in the carbon stocks are estimated. The activities to be implemented under each step are presented below.

a) Monitoring of the project initiation

The project monitoring should take into account the activities initiated after the project start date. It should focus on the following aspects.

- Field surveys shall be conducted at periodic intervals to verify that the permanent markers used to delineate the project boundary and various geographic units can be located on the ground;
- Depending on the availability of technology and resources, it is recommended to use GPS, remote sensing, and aerial photo evidence to record the size, geographic locations and boundaries of the sites and species planted on the sites;
- Methods for identification of the project boundary should be incorporated in the Monitoring Plan in order to evaluate the land use and economic activities that occur outside the project boundary and which can influence the project over the crediting period;
- Monitoring measures to assess the risk of fire shall be implemented;
- Procedures used in monitoring of the project activities are subject to quality assurance/ quality control measures;
- Personnel involved in the monitoring shall be trained in the early stage of the project so that they are equipped to implement the steps and procedures of the monitoring process.

b) Monitoring of the area afforested or reforested

The area afforested under the project shall be monitored and provisions for collection of information shall be included in the monitoring plan as follows.

- Information on the species composition, area planted and characteristics of strata and substrata shall be recorded;
- The spacing adopted at the level of the stands or geographic units, and the deviation, if any, from the recommended spacing shall be recorded;
- The information on supplemental plantings undertaken to fill the gaps, and their area and, location shall be identified on the maps;
- Information on the occurrence of droughts, fires, and floods etc. and the area affected by them shall be recorded. In case of fires, the causes, area affected, season, and duration of fire occurrence shall be recorded and the emissions associated with the burning of biomass shall be calculated and accounted as part of project emissions;

c) Monitoring of the forest establishment

The following aspects shall be monitored during the establishment period covering the first three years of the project.

- Information on planting dates, drainage, frost, and other climatic extremes that can impact stand establishment and stand growth shall be recorded;
- For site preparation, type of site preparation, the area affected, and amount of vegetation removed in site preparation should be documented, and the emissions from the loss of biomass activities shall be calculated and accounted as part of project emissions;
- Weeding and tending practices influence the competition and establishment of the seedlings. Therefore, the number and periodicity of weedings and the use of herbicides shall be recorded;
- Survival rates of planted stock should be established by undertaking surveys during the initial establishment period;
- The survival percent established after the 3rd year should be recorded and reported.

d) Monitoring of forest management activities

The information on forest management activities such as thinning, tending, fertilization, harvesting, and other silvicultural operations that influence the GHG removals by sinks shall be collected. The types of activities that need to be monitored in this context are:

- Biomass removed in thinning and harvest, including the disturbance associated with thinning and harvesting, shall be monitored and recorded;
- Quantity of fossil fuels used in silviculture, transport, and other management activities shall be recorded and the quantity of fossil fuels used for each operation in a year shall be calculated and archived;
- Amount of organic and synthetic fertilizer applied and the time of application shall be recorded in order to estimate the GHG emissions associated with fertilizer application;
- Information on the occurrence of fires or other natural or human induced disturbances and the area and biomass affected shall be recorded and reported;
- Deviations between the field practices implemented and the ones outlined in the project design document, and reasons for the deviations shall be recorded.

e) Monitoring frequency

A 5-year monitoring frequency is considered adequate for the vegetation pools. To ensure that the monitoring frequency adequately reflects the changes in carbon pools, changes observed in each pool during the monitoring interval shall be recorded. For soil carbon pool that is likely to change slowly, the monitoring frequency can range from 10 to 20 years. In situations where the project adopts a 20-year renewable crediting period, soil monitoring frequency should be fixed to coincide the crediting period.

2. Stratification and sampling for ex-post calculations

a) Stratification

Stratification helps to group the project plots into homogenous units of sub-strata and strata. The factors that directly influence the carbon pools such as rainfall, soil type, erosion, site quality, species type, stand structure, land use, management regime etc. can be relevant in the stratification of project area.

The following steps shall be considered in implementing the stratification.

Step 1: Factors that significantly influence the carbon stocks of the project area shall be considered in the stratification. These could include physiographic features, soil type, species, year of planting, and anthropogenic influences, etc.

Step 2: Data and information on the location specific factors should be collected from surveys, project specific studies, and official sources and could include:

- land use maps from official sources, satellite imagery, aerial photographs or data collected from field surveys;
- soil and cadastral maps showing physiographic features, geology, soil type, soil texture, and incidence of erosion;
- data on vegetation characteristics such as species type, composition, and density; and
- information on anthropogenic influences and socio-economic factors specific to the region.

Step 3: Stratification should follow the order of hierarchy of variables that have wider influence (e.g. rainfall) followed by variables that are specific to a geographic unit (e.g. soil type). Alternatively, spatial data methods such as GIS could be used as substitutes to the hierarchical approach by overlaying the project level spatial information for identifying the strata.

Step 4: At the time of delineating strata, the characteristics specific to a stratum shall be identified and used to corroborate the information from the preliminary stratification. The following categories of variables shall be relevant in this context.

- Vegetation characteristics such as species, density, composition, and growth as reflected in the diameter at breast height and height. Depending on the density of tree vegetation, 3 to 5 plots of 400 m^2 representing each preliminary stratum can be selected;
- Field surveys should be undertaken in order to account for the specific anthropogenic influences such as fuelwood collection, non-timber product gathering, and other land use practices.

Step 5: Information on the carbon pools shall be assessed taking into account the size of stratum and the variability in the carbon pools observed in each stratum.

Step 6: The sub-strata of each stratum should be based on planting year or species cohorts, should the plantings occur over several years as per the plan of planting sequence outlined in the PDD;

Step 7: A stratification map shall be prepared outlining the project boundaries, species composition, and year of planting. Depending on the feasibility, GIS methods could be used in the stratification.

Post stratification shall be allowed during the project, if this leads to greater accuracy of monitoring results, or can help reduce costs at same levels of accuracy.

(b) Sampling

The project participants shall take into account the number of strata, their variability, and the proportion of stratum area to the project area and the tolerable error in defining the sample frame.

This methodology recommends the use of permanent sample plots for sampling and measurement of carbon pools since permanent sample plots are cost effective and efficient in estimating the changes in carbon stocks, and permit physical verification using either the permanent plot markers or the GPS. It is recommended to layout the plots on homogenous soil type with adequate access and sufficient long-term security from human disturbance. With permanent sample plots, it is recommended to use nested plot approach, which permits efficient measurement of tree growth through time.

The plot markers of permanent plots should not be prominently displayed to ensure that the sample plots do not receive differential treatment. The demarcation of plot corners of rectangular plots helps to delimit the boundaries for above-ground biomass measurements. If GPS is used to demarcate the plot, the GPS coordinates could be used to identify the centres of circular plots that can be used for soil sampling.

Above-ground tree vegetation: Considering the large covariance between observations at successive sampling events, the permanent sample plots are efficient in estimating the changes in above-ground biomass pool. Permanent sample plots also facilitate the continuity of monitoring events as the tree vegetation grows and permit the development of plot and management histories on the tree vegetation.

Non-tree vegetation: Considering the short turnover time of non-tree vegetation, temporary plots within the nested plots shall be used and destructive sampling is used to estimate the non-tree vegetation.

Litter: A frame of constant size (e.g. 30 cm radius) is used to sample the litter. The frames can be located at four corners of the larger tree sampling plots to measure the litter biomass.

Soil: Sampling frequency shall take into account the changes in soil carbon. In order to minimize the monitoring costs, soil carbon measurements shall be undertaken at the beginning of the project and between 10 to 20-year intervals. If 20-year interval is adopted, it can be used to coincide with the 20-year crediting period for projects adopting the renewable crediting period. If desired, the changes in soil carbon pool could also be monitored more frequently.

Sample frame to target 10% precision level

A precision level of 10% in the mean with a 95% confidence interval shall be used to estimate the carbon pools. The total error includes the errors from sampling, measurement, and other errors and unexplained variation. Sampling error accounts for more than 3/4 of the total error. Therefore, in order to achieve a 10% precision level**,** a 7% sampling error needs to be targeted and the remaining 3% error includes other types of errors. By increasing the sample size and the plot size, it is possible to increase the precision and decrease the variability of the estimate. Within the overall precision level of 10%, different precision levels could be defined for individual pools taking into account the variation observed in respective pools.

(i) Determination of sample size

The sample size in each stratum depends on the targeted precision level, project area and standard deviation of the carbon pools in each stratum. The variance of each stratum and area of stratum shall be considered in determining the sample size. Increasing the sample size serves to refine the estimates around the mean. The samples size (n) can be estimated as per the Neyman criterion of fixed levels of costs and accuracy and the number of plots in each stratum/sub-stratum can be calculated using the following equation.

The sample size for *n* strata can be calculated as follows.

$$n = \left(\frac{t_{\alpha/2}}{A}\right)^2 \left(\sum_{i=1}^{N_I} W_i s_i \sqrt{C}_i\right)\left(\sum_{i=1}^{N_s} W_i s_i \Big/ \sqrt{C_i}\right) \qquad \textbf{(M.1)}$$

where:

n	sample size (number of sample plots required for monitoring)
$t_{\alpha/2}$	value of the Student t statistic, for α = 0.05 (implying a 95% confidence level)
N_S	total number of strata defined
Ni	number of potential sample units (permanent sample plots) in stratum *i*
N	total number of potential sample units (permanent sample plots)
s_i	standard deviation in stratum *i*
A	permissible error in the mean
Ci	cost of selecting a sample plot in stratum *i*
$Wi = N_i / N_s$	

The number of plots shall be allocated among the strata

$$n_h = n \bullet p_i \quad \text{and} \quad p_i = \left(W_i s_i / \sqrt{C_i}\right) \Big/ \left(\sum_{i=1}^{Ns} W_i s_i \Big/ \sqrt{C_i}\right) \qquad \textbf{(M.2)}$$

where:

n_i is the number of samples to be allocated in stratum *i*.

The allowable error is a value on per-plot basis estimated as ±10% of the mean biomass carbon stock per plot. The sample size is allowed to change in the future, if variation in the carbon stock changes is observed.

(c) Allocation of plots

Allocation of permanent sample plots to the geographic units or the planting sites shall be done by selecting a random start and assigning plots to planting sites. Within each geographic unit or planting site, plots shall be located systematically, with number of plots corresponding to the planting site by superimposing a grid over the site map.

(d) Plot area

Plot area has major influence on the sampling intensity and the resources spent on the field measurements. It depends on the stand density. Therefore, increasing the plot area decreases the variability between two samples. According to Freese (1962)[16], the relationship between plot area and its coefficient of variation can be denoted as follows.

$$CV_2{}^2 = CV_1{}^2 \sqrt{(P_1 / P_2)} \qquad \textbf{(M.3)}$$

Where, P_1 and P_2 represent plot areas and their corresponding coefficient of variation (CV). Thus, an increase in the plot area reduces variation among the plots, and permits the use of small sample size at the same level of precision. The coefficient of variation of basal area increases as sample plot size decreases below 0.4 ha. Therefore, the areas of different strata shall be used to determine the optimum plot area that minimizes the coefficient of variation. The relationship between plot size and sample size can be used to determine the sampling strategy that minimizes the cost of monitoring.

(e) Plot location

The plots should be located systematically with random start location permits uniform representation of sub-strata and strata of project area. The plot location shall be marked using either permanent markers or GPS. The use of GPS facilitates easier identification of plots with the use of GPS coordinates.

Depending on vegetation density, the size of plots can vary from 100 m^2 for dense stands to 1000 m^2 for open stands. If a stratum consists of several dispersed geographic units, the number of plots and average plot area are estimates as follows:

- stratum area is divided by number of plots to estimate the average area per plot; and
- area of each planting site shall be divided by average area of the plot, and rounded to the nearest integer.

3. Calculation of ex post baseline net GHG removals by sinks, if required

Under this methodology, there is no need for monitoring the baseline.

4. Data to be collected and archived for of baseline net GHG removals by sinks

Under this methodology, there is no need for monitoring the baseline.

5. Calculation of ex post actual net GHG removal by sinks

The changes in the carbon stocks since the start of the project are represented as below.

$$\Delta C_{ACTUAL,t} = \sum_i \sum_j \sum_k \left[\Delta C_{ijk,t} - GHG_{E,t}\right] \qquad \textbf{(M.4)}$$

where:

ΔC_{ACTUAL}	actual net greenhouse gas removals by sinks in t CO_2-eq yr^{-1} for year t
$\Delta C_{,\,ijk,t}$	average annual change in carbon pools for stratum *i* sub-stratum *j* species *k* in t CO_2 yr^{-1} for year *t*.

[16] Freese, F. 1962. Elementary Forest Sampling. USDA Handbook 232. GPO Washington, DC. 91 pp

GHG_E	GHG emissions by sources within the project boundary as a result of the implementation of an A/R CDM project activity in t CO_2-eq yr^{-1} for year t
t	year 1 to the end of crediting period
i	stratum
j	substratum (age class)
k	species

(a) Verifiable changes in carbon stocks in the carbon pools

This methodology covers the monitoring of the following pools:

1. above-ground biomass
    a. tree component;
    b. non-tree component;
2. below-ground biomass;
3. deadwood;
4. litter; and
5. soil

The verifiable changes in the ***ex-post*** biomass carbon stocks shall be calculated by applying the stock change method to the data collected at the monitoring intervals.

$$\Delta C_{ijk,t} = [\Delta C_{ABijk,t} + \Delta C_{BBijk,t} + \Delta C_{DWijk,t} + \Delta C_{Lijk,t} + \Delta C_{SOC\ ijk,t}] \bullet [44/12] \quad \textbf{(M.5)}$$

where:

$\Delta C_{,ijk,t}$	verifiable annual changes in the carbon stock of pools for stratum *i* sub-stratum *j* species *k* in t CO_2-eq yr^{-1} in year *t*
$\Delta C_{AB,ijk,t}$	verifiable annual changes in the carbon stock of aboveground biomass for stratum *i* sub-stratum j species *k* in t C yr^{-1} in year *t*
$\Delta C_{BB,ijk,t}$	average annual changes in the carbon stock of belowground biomass for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year *t*
$\Delta C_{DW,ijk,t}$	average annual changes in the carbon stock of deadwood for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year t
$\Delta C_{L,ijk,t}$	average annual changes in the carbon stock of litter for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year *t*
$\Delta C_{SOC,ijk,t}$	average annual changes in the carbon stock of soil organic matter for stratum *i* substratum *j* species *k* in t C yr^{-1} in year *t*
44/12	ratio of molecular weights of carbon and CO_2, dimensionless

Table 5: Direction of change in the *ex-post* carbon pools of the project

Degraded land	AGB-tree,	AGB- non-tree	Below-ground biomass	Dead wood	Litter	Soil
Size of the pool	Significant	Herb – insignificant Shrub – significant / insignificant	Significant	Early period - insignificant Later period - significant	Significant	Significant over 10 to 20-year period
Direction of change	Increase	Increase / unchanging	Increase	Increase	Increase	Increase
Expected net change in carbon stock	Positive	Positive / unchanging	Positive	Positive	Positive	Positive
Carbon pool to measure	Yes	Yes	Yes	Yes	Yes	Yes

Note: AGB – Above-ground biomass

a.1 Changes in the carbon stocks of above-ground biomass

The changes in the *ex-post* actual carbon stocks of above ground biomass shall be calculated from the inventory and measurement data collected from two consecutive monitoring intervals.

$$\Delta C_{AB,ijk,t} = (C_{AB,m_2,ijk} - C_{AB,m_1,ijk})/T_B \quad \textbf{(M.6)}$$

$$C_{AB,m,ijk} = A_{m,ijk} \bullet MC_{AB\_m,ijk} \quad \textbf{(M.7)}$$

where:

$\Delta C_{AB,ijk}$	average annual changes in carbon stock of aboveground biomass for stratum *i* sub-stratum *j* species *k* in t C yr^{-1} in year t
$C_{AB,m2,ijk}$	carbon stock of aboveground biomass for stratum *i* sub-stratum *j* species *k* calculated at monitoring event m_2 in t C
$C_{AB,m1,ijk,t}$	carbon stock of aboveground biomass for stratum *i* sub-stratum *j* species *k* calculated at monitoring event m_1 in t C
$A_{m,ijk}$	area of stratum *i* sub-stratum *j* species *k* at monitor event *m* in ha
$MC_{AB,m,ijk}$	average carbon stock of above ground biomass for stratum *i* sub-stratum *j* species *k* at monitoring event *m* in t C ha^{-1}
T_B	time in years between monitoring events m_2 and m_1 of the biomass monitoring.

The average carbon stock of above ground biomass is the sum of changes in the tree and the non-tree components.

$$MC_{AB,m,ijk} = MC_{AB\_Tree_{m,ijk}} + MC_{AB\_NTree\_Shrub_{m,ijk}} + MC_{AB\_NTree\_Herb_{m,ijk}} \quad \textbf{(M.8)}$$

where:

$MC_{AB\_Tree,m,ijk}$ average carbon stock of aboveground tree biomass in stratum *i* sub-stratum *j* species *k* at monitoring event *m* in t C ha^{-1}

$MC_{AB\_NTree\_Shrub,m,ijk}$ average annual change in carbon stock of aboveground non-tree shrub component in stratum *i* sub-stratum *j* species *k* at monitoring event *m* in t C ha^{-1}

$MC_{AB\_NTree\_Herb,m,ijk}$ average annual change in carbon stock of aboveground non-tree herb component in stratum *i* sub-stratum *j* species *k* at monitoring event *m* in t C ha^{-1}

The monitoring procedures to be used in calculating the changes in carbon stocks of tree and non-tree components of above-ground biomass are presented below.

The average carbon stock of tree, shrub, and herb biomass for each stratum shall be calculated by averaging across the plots in a stratum or sub-stratum as outlined below.

$$MC_{AB\_Tree,m,ijk} = \frac{\sum_{p=1}^{P_{ijk}} C_{AB\_Tree,m,ijk,p}}{P_{ijk}} \quad \textbf{(M.9)}$$

$$MC_{AB\_NTree\_Shrub,m,ijk} = \frac{\sum_{p=1}^{P_{ijk}} C_{AB\_NTree\_Shrub,m,ijk,p}}{P_{ijk}} \quad \textbf{(M.10)}$$

Note: the subscripts ij refers to the strata and sub-strata of planted tree species

$$MC_{AB\_NTree\_Herb,m,ijk} = \frac{\sum_{p=1}^{P_{ijk}} C_{AB\_NTree\_Herb,m,ijk,p}}{P_{ijk}} \quad \textbf{(M.11)}$$

Note: the subscripts ij refers to the strata and sub-strata of planted tree species

where:

$C_{AB\_Tree,m,ijk,p}$ plot level above-ground tree carbon stock in stratum *i* substratum *j* species *k* at monitoring event *m* in t C ha^{-1}

$MC_{AB\_NTree\_Shrub,m,ijk,p}$ plot level above-ground non-tree shrub carbon stock in stratum *i* substratum *j* species *k* at monitoring event *m* in t C ha^{-1}

$MC_{AB\_NTree\_Herb,m,ijk,p}$ plot level above-ground non-tree herb carbon stock in stratum *i* substratum *j* species *k* at monitoring event *m* in t C ha^{-1}

p plot number in stratum *i*, substratum *j* species *k*

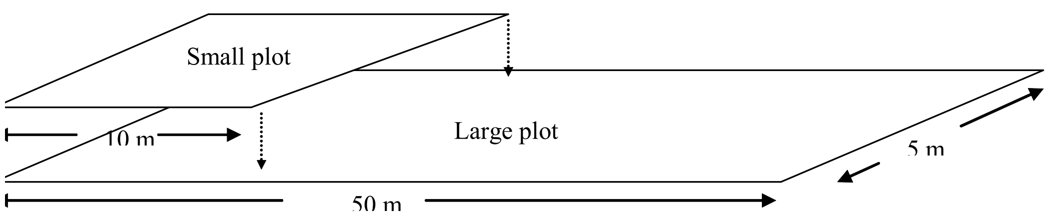
P_{ijk} number of plots in stratum *i* substratum *j* species *k*

a.1.1 Above-ground tree biomass ($C_{AB\_Tree,}$)

The changes in tree biomass are calculated from the monitoring data on individual trees in the permanent sample plots. The plots are established along transects and the diameter at breast height (dbh) at 1.3 m is measured. In addition to diameter measurement, height of the tallest trees is measured to confirm the site class. Periodic checks of the data shall be performed by verifying tree height.

Nested plots are suitable for monitoring the changes in the diameters and the stand density. A nested plot comprises small plots nested in a large plot. The large plots should have at least 10 stems in a lightly stocked stand. All stems over 10 cm dbh are measured and recorded in the plot. This represents an area of 250 m^2 (10 X 25 m^2 per stem). Small plots are used to record the stems of small dimensions (for example, ≤ 10 cm dbh, ≥ 2 cm). The size of a small plot is 50 m^2 (10m X 5m) and should capture at least 10 stems (**Figure 1**). Since small and large plots measure the same number of stems per plot, the inter-plot variability in t C/ha is about the same for both plot sizes.

Figure 1 Nested plot layout



In order to efficiently sample the vegetation, measurements in the nested plot can start from a corner and move in a specified N/S or E/W direction. The biomass stocks of the tree component shall be estimated using the measurements on diameter at breast height (dbh) and height. The measurements at two monitoring intervals enable the estimation of changes in the biomass using stock change method. Locally available allometric equations should be used or equations for site class and species should be developed through destructive sampling.

(1) Allometric equation method

The species-specific and local allometric equations should be considered on priority. In the absence of local allometric equations, if allometric equations developed from biome-wide data are considered, such equations should be verified by comparing the biomass estimates of destructively harvested trees of different diameter classes within the project area. If the biomass estimated from the harvested trees is within about ±10% of that predicted by the equation, then the selected equation can be considered suitable for the project. If this is not the case, it is recommended to develop local allometric equations for the project use from destructive sampling of trees randomly selected in each age class.

Step 1*:* The diameter at breast height (DBH) and preferably height of trees above a minimum DBH in the plots representative of the strata should be measured.

Step 2: The dominant tree species covering all diameter classes are selected and their DBH and height are measured. A standard tree with mean DBH, tree height, crown diameter and height of living crown shall be selected to calculate the mean basal area or mean volume.

Step 3: The dry weight measurements of tree components are recorded in order to calculate the above- and below-ground biomass of the standard tree.

Step 4: The carbon stock of per tree above-ground biomass can be estimated by relating the biomass to either DBH or DBH and height using selected allometric equations applied to the tree measurements in Step 1 and multiplying the carbon fraction of tree biomass.

$$C_{AB\_Tree_k} = f(DBH_k, H_k) \bullet CF_k \qquad \textbf{(M.12)}$$

where:

$C_{AB\_Tree_k}$ = carbon stock of above-ground tree biomass of species k in t.d.m. ha^{-1}

$f(DBH_k, H_k)$ = allometric equation linking merchantable volume to the mean diameter at breast height (DBH) in meters and tree height (H) meters.

Step 5: The above-ground biomass carbon per plot on a per area basis should be calculated by summing the biomass carbon per tree within each plot and multiplying with the plot expansion factor which is proportional to the area of the measurement plot and then divided by 1,000 to convert from kg to tonnes.

$$C_{AB\_Tree,m,ijk,p} = \frac{\left(\sum_{tr=1}^{TR} C_{AB,Tree,m,ijk} \cdot XF \right)}{1000} \qquad \textbf{(M.13)}$$

$$XF = \frac{10{,}000}{A_p} \qquad \textbf{(M.14)}$$

where:

C_{AB_Tree,m,k,p_k} plot level above ground tree carbon stock of stratum i sub-stratum j species k plot p at monitoring event m in t C ha^{-1}

XF expansion factor to represent the per plot value to per hectare value

A_p Plot area in m^2

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

Step 6: The average carbon stock of tree biomass for each stratum is calculated by averaging across the plots in a stratum or sub-stratum and is represented in the equation M.9.

(2) Biomass expansion factor method

The changes in above-ground tree biomass shall be assessed using data on the diameter at breast height (dbh) and the height from the monitoring event, and the biomass expansion factors of species.

Step 1: The diameter at breast height (dbh) above a minimum threshold value and the tree height measured should be used to estimate the merchantable volume.

Step 2: The volume of the commercial component of trees based on locally derived equations shall be calculated and sum for all trees within a plot and expressed as volume per unit area (m^3/ha).

Step 3: The biomass expansion factor (BEF) required for the conversion of merchantable volume into above-ground biomass and below-ground biomass shall be obtained from published sources. Since biomass expansion factors (BEF) are age dependent, with young stands corresponding to the large BEF and old stands to the small BEF, caution shall be exercised in using the generic expansion factors.

Step 4: The merchantable volume of the above-ground tree biomass component is multiplied with the basic density of wood, biomass expansion factor of the species and carbon fraction of tree biomass to estimate the carbon stock of above-ground tree biomass.

$$C_{AB\_Tree_{m,ijk,p}} = V_{Tree,m,ijk,p} \bullet D_k \bullet BEF_{jk} \bullet CF_k \qquad \textbf{(M.15)}$$

where:

$C_{AB\_Tree,m,ijk}$ carbon stock of above-ground tree biomass of stratum *i* sub-stratum *j* species *k* plot *p* at monitoring event *m* in t C.ha^{-1}

$V_{Tree,m,ijk}$ merchantable tree volume of stratum *i* sub-stratum *j* species *k* plot *p* at monitoring event *m* in m^3.ha^{-1}

D_k basic wood density of the species *k* in t.d.m. m^{-3}

BEF_{jk} biomass expansion factor for the species *k* to convert merchantable volume to above-ground biomass, dimensionless

CF_k carbon fraction of above ground tree biomass of species *k*, dimensionless

a.1.2 Non-tree biomass (C_{AB_NTree})

The non-tree biomass comprises shrub and herb biomass. It is possible to omit non-tree woody biomass in the ex-ante estimation, provided that it is conservative. If non-tree biomass is monitored, it is recommended to use the local definitions on herb and shrub biomass. The definitions from Good Practice Guidance on LULUCF could be used, if local definitions are not readily available.

Shrub biomass

It is good practice to estimate the removal factors for shrubs and woody perennials using local data or adopting default carbon accumulation factors for shrubs that are relevant to the project. If the shrub component is significant, the shrub biomass regressions shall be developed as part of the monitoring process.

Step 1*:* Estimation of carbon stock of shrub biomass ($C_{AB,NTree\_Shrub,p}$)

Sub-step 1a: For small shrubs, measurement of shrub biomass shall be done using destructive methods. A small plot of 0.3m to 1.0m radius could be established in the permanent sample plot and all the shrub vegetation is harvested, weighed, and over dried to estimate the dry biomass.

Sub-step 1b: For large shrubs, the parameters of height and diameter shall be measured to estimate the shrub biomass. If no allometric equations are readily available, it is *good practice* to develop allometric equations or to adopt existing allometric equations available in the region. The allometric equations for shrubs can be constructed using the variables such as diameter at base (DB), shrub height (H), crown area (CA) and the number of stems (N).

$$C_{AB\_NTree\_Shrub_{ijk,p}} = f_k(DB, H, CA, N) \bullet CF_{Shrub} \qquad \textbf{(M.16)}$$

Note: Under this methodology, ij refer to the shrubs present in the stratum and substratum (age class) of planted tree species

where:

$C_{AB\_NTree\_Shrub,m,ijk,p}$ carbon stock of above-ground shrub biomass for tree stratum *i* sub-stratum *j* species *k* plot *p* at monitoring event *m* in t C.ha^{-1}

$f_k(DB, H, CA, N)$ allometric equation linking above-ground biomass (d.m. ha^{-1}) of shrubs to diameter at base (DB), shrub height (H), crown area (CA) and number of stems per hectare (N)

CF_{Shrub} carbon fraction of the above ground shrub biomass, dimensionless

Step 2*:* Estimation of carbon stock of herb biomass ($C_{AB\_NTree\_Herb,p}$)

The herb biomass represents a small proportion of the total biomass pool in the project and it is often higher or comparable to the herb biomass observed in the baseline scenario. In such situations, the herb biomass need not be monitored considering the monitoring costs involved. However, when herb biomass is estimated, the following steps shall be followed.

Sub-step 2a: A circular frame of 0.30 to 1 .00m radius or square frame of 0.30 to 1.00m is used to collect the herbaceous biomass and the wet weight is recorded.

Sub-step 2b: The biomass is oven dried and laboratory analysis is conducted to estimate the carbon content.

Sub-step 2c: To estimate the dry litter carbon in tonnes per ha, the carbon from step 2b is multiplied by the expansion factor (10,000 m^2/ plot area in m^2).

$$C_{AB\_NTree\_Herb_{ijk,p}} = C_{AB\_NTree\_Herb\_wet_{ijk,p}} \bullet (1 - MP_{ijk}) \bullet (1/a_{ijk}) \bullet (1/100) \qquad \textbf{(M.17)}$$

where:

$C_{AB\_NTree\_Herb,ijk,p}$ carbon in dry above-ground herb biomass for stratum *i* substratum *j* (age class of trees) and tree species *k* for plot *p* in t C·ha^{-1}

$C_{AB\_NTree\_Herb\_wet,ijk,p}$ carbon in wet above-ground herb biomass for stratum *i* substratum *j* (age class of trees) and tree species *k* for plot *p* in g·m^{-2}

a_{ijk} = area of sampling frame for stratum *i* substratum *j* (age class of trees) and tree species k in m^2

MP_{ijk} = weight fraction of moisture in the herb biomass for stratum *i* substratum *j* (age class of trees) and tree species *k* (0 to 1) [(wet weight – dry weight)/wet weight]

Sub-step 2d: The average carbon stock of herb biomass for each stratum is calculated by averaging across the plots in a stratum or sub-stratum and is represented in the equation M.11

a.2 Below-ground biomass (C_{BB})

The below-ground biomass pool can be estimated from the above-ground biomass using the root-to-shoot ratio. This ratio shall be either calculated from the destructive sampling data or obtained from the local/national studies that closely reflect the conditions of the project activity. If local/national data are not available, the root-to-shoot value in the Good Practice Guidance on LULUCF (IPCC 2003) shall be used.

Step 1: The carbon stock of below ground biomass is calculated as a product of above ground biomass of tree, shrub and herb components and the root-shoot ratio of the species in the respective components.

$$C_{BB,m,_{ijk}} = A_{m,ijk} \bullet MC_{BB,m,ijk} \qquad \textbf{(M.18)}$$

$$MC_{BB,m,_{ijk}} = A_{m,ijk}[MC_{AB\_Tree_{m,ijk}} \bullet R_{T,jk}] + [MC_{AB\_NTree\_Shrub,m,ijk} \bullet R_S] + C_{AB\_NTree\_Herb,m,ijk} \bullet R_H \qquad \textbf{(M.19)}$$

where:

$A_{m,_{ijk}}$ = area of stratum *i* sub-stratum *j* species *k* at monitoring time *m* in ha
$MC_{BB,m,ijk}$ = average carbon stock of below ground biomass for stratum *i* sub-stratum *j* tree species *k* at monitor time *m* in t C ha^{-1}
$R_{T,\ jk}$ = root-shoot ratio for tree species *k* age class *j*, dimensionless
R_S = root-shoot ratio for shrub, dimensionless
R_{Hi} = root-shoot ratio for herb, dimensionless

Step 2: The average annual carbon stock change in the below ground biomass is estimated from the data on carbon stock measurement at two monitoring intervals.

$$\Delta C_{BB,_{ijk},t} = (C_{BB,m_2,ijk} - C_{BB,m_1,ijk}) \big/ T_B \qquad \textbf{(M.20)}$$

where:

$C_{BB,ijk,t}$ average annual carbon stock change in the below-ground biomass in stratum *i* sub-stratum *j* species *k* in t C. yr^{-1} in year t
$C_{BB,m2,ijk}$ carbon stock of the below-ground biomass for stratum *i* sub-stratum *j* species *k* calculated at monitoring event m_2 in t C
$C_{BB,m1,ijk}$ carbon stock of the below-ground biomass for stratum *i* sub-stratum *j* species *k* calculated at monitoring event m_1 in t C
T_B time in years between monitoring events m_2 and m_1 of the biomass monitoring.

a.3 Deadwood (B_{DW})

Deadwood observed in the field comprises two components – *standing deadwood* and *lying dead wood*. Considering the differences in two components, different sampling and estimation procedures should be used to calculate the changes in deadwood biomass of the two components.

In addition to the standing and the lying deadwood components that are observable in the field, deadwood also occurs below the ground. The below-ground deadwood has different rates of decomposition in comparison to the decomposition rates of standing and lying deadwood. The below-ground deadwood of the project is expected to contribute to the increases in carbon stocks. Therefore, non-accounting of this component is considered conservative under this methodology.

$$\Delta C_{DW\,ijk,t} = (C_{DW_{m_2,ijk}} - C_{DW_{m_1,ijk}})/T_W \qquad \textbf{(M.21)}$$

$C_{DW,ijk,t}$ average annual change in the biomass of deadwood in stratum *i* sub-stratum *j* species *k* in t C.

$C_{DW,m2,ijk}$, carbon stock of deadwood in stratum *i* sub-stratum j species k at monitoring event m_2 in t C

$C_{DW,m1,ijk}$ change in the biomass of deadwood in stratum *i* sub-stratum *j* species *k* at monitoring event m_1 in t C

T_{DW} monitoring interval for dead wood $T_{DW} = T_B = m_2 - m_1$ in years

The methods to be followed in the measurement of the standing deadwood and the lying deadwood biomass are outlined below.

$$C_{DW\,m,ijk} = [\ B_{SDW_{m,ijk}} + B_{LDW_{m,ijk}}\ ] \bullet CF_{DW} \qquad \textbf{(M. 22)}$$

where:

$C_{DW,m,ijk}$ carbon stock of deadwood biomass in stratum *i* sub-stratum *j* species *k* at monitoring event *m* in t C

$B_{SDW,m,ijk}$ biomass of standing deadwood in stratum *i* sub-stratum *j* species *k* at monitoring event *m* in t.d.m.

$B_{LDW,m,ijk}$ biomass of lying deadwood in stratum *i,* sub-stratum *j* species *k* at monitoring event *m* in t.d.m.

CF_{DW} carbon fraction of dead wood, dimensionless

(1) Standing dead wood

Step 1: Standing dead trees shall be measured using the same criteria and monitoring frequency used for measuring live trees. The decomposed portion that corresponds to the original living biomass is discounted.

Step 2: The decomposition class of the dead tree and the diameter at breast height shall be recorded and the standing dead wood is categorized under the following four decomposition classes.

1. Tree with branches and twigs that resembles a live tree (except for leaves)
2. Tree with no twigs but with persistent small and large branches
3. Tree with large branches only
4. Bole only, no branches

Step 3: Biomass should be estimated using the allometric equation for live trees in the decomposition class 1. When the bole is in decomposition classes 2, 3 or 4, it is recommended to limit the estimate of the biomass to the main trunk of the tree.

Step 4: The volume of deadwood is converted to biomass using the appropriate dead wood density class. If the top of the standing dead tree is missing, the height of the remaining stem is measured and the top diameter is estimated as the ratio of the top diameter to the basal diameter.

(1) Lying dead wood

The lying dead wood pool is highly variable in young stands and it increases as the stands grow. If there is negligible amount of lying dead wood observed in the early stages of a stand, its monitoring could be taken up in the second or subsequent monitoring periods. The information on the occurrence of lying deadwood can be assessed from the plot surveys.

Step 1: Lying deadwood should be sampled using the line intersect method (Harmon and Sexton, 1996)[17]. Two 50-meter lines are established bisecting each plot and the diameters of the lying dead wood (≥ 5 cm diameter) intersecting the lines are measured.

Step 2: The dead wood is assigned to one of the three density states (sound, intermediate, and rotten).

Step 3: Volume of lying deadwood per unit area is calculated using the equation (Warren and Olsen, 1964)[18].

$$V_{LDW\,m,ijk} = 9.869 \bullet (D_{ijk}{}^{2} / 8) \bullet L \qquad \textbf{(M.23)}$$

where:

$V_{LDW,m,ijk}$	volume of lying deadwood in stratum *i* sub-stratum *j* species k in m^3/m^2
$D^2{}_{,ijk}$	squared diameter of pieces of dead wood in stratum *i* sub-stratum *j* species *k* in
L	length of the transect in m

Step 4: Volume of lying deadwood shall be converted into biomass using the following relationship.

$$B_{LDW\,m,ijk} = A_{ijk} \bullet \sum_{dc=1}^{3} V_{LDW,m,ijk} \bullet D_{DW,dc} \bullet 10 \qquad \textbf{(M.24)}$$

where:

$B_{LDW,m,ijk}$	biomass of lying deadwood in stratum *i* sub-stratum *j* species *k* at monitoring event *m* in t.d.m.
$D_{DW,dc}$	basic density of dead wood in the density class – sound (1), intermediate (2), and rotten (3) in $kg.d.m/m^3$
A_{ijk}	Area of stratum *i* substratum *j* species *k* in ha

a.4 Litter (C_L)

Litter includes all dead biomass of less than 10cm diameter and dead leaves, twigs, dry grass, and small branches. The litter accumulation is a function of annual amount of litter fall minus the annual rate of decomposition. During early stages of stand development, litter increases rapidly and

[17] Harmon, M. E. and J. Sexton. (1996) Guidelines for Measurements of Woody Detritus in Forest Ecosystems. US LTER Publication No. 20. US LTER Network Office, University of Washington, Seattle, WA, USA.

[18] Warren, W.G. and Olsen, P.F. (1964) A line transect technique for assessing logging waste, *Forest Science* 10: 267-276.

stabilizes during the later part of the stand. Therefore, litter samples shall be collected at the same time of the year in order to account for natural and anthropogenic influences on the litter accumulation and to eliminate seasonal effects.

Step 1: Litter shall be sampled using a 30cm radius circular frame. The frame is placed at four locations of plot corners within the small nested plot (10m X 5m).

Step 2: At each location, all litter (leaves, fruits, small wood, etc.) falling inside the frame shall be collected and the litter from four locations is mixed to get a representative sample for measuring the wet weight of the biomass.

Step 3: The litter is oven dried and weighed to determine the dry weight. The moisture fraction of biomass weight is estimated by calculating the difference between the weights of wet and dry weight to the wet weight of litter biomass.

Step 4: The wet biomass is oven dried to estimate the dry biomass. To estimate the dry litter biomass in tonnes per ha, the wet litter biomass is multiplied by the moisture proportion and expansion factor for the plot size to calculate the litter biomass per ha (10,000 m^2/ area of plot in m^2).

$$C_{L_{m,ijk}} = A_{ijk} \bullet C_{L\_wet_{m,ijk}} \bullet (1 - MP_L) \bullet (1/a_{ijk}) \bullet (1/100) \qquad \textbf{(M.25)}$$

where:

$C_{L,m,ijk}$	carbon in dry litter biomass at monitor time *m* in t·C
$C_{L\_wet,m,ijk}$	carbon in wet litter biomass at monitoring time *m* in $g{\cdot}m^{-2}$
MP_L	weight fraction of moisture of litter biomass (0 to 1) [(wet weight – dry weight)/wet weight], dimensionless
a_{ijk}	area of sampling frame in m^2

Step 5: The average annual change in the carbon stock of litter from the data at two monitoring intervals shall be calculated. As recommended in the Good Practice Guidance on LULUCF (Chapter 3.2, p 3.35), the dry mass of litter is converted into carbon using 0.370 as default value[19] instead of the default carbon fraction (0.5) used for biomass.

$$\Delta C_{L_{ijk,t}} = [(C_{L_{m_2,ijk}} - C_{L_{m_1,ijk}})/T_L] \bullet CF_L \qquad \textbf{(M.26)}$$

where:

$\Delta C_{L,m,ijk,t}$	average annual change in the biomass of litter in stratum *i* sub-stratum *j* species k at monitoring event *m* in t C yr^{-1}.
$C_{L,m2,ijk}$	carbon stock of litter in stratum *i* sub-stratum *j* species *k* at monitoring event m_2 in t C
$C_{L,m1,ijk}$	change in the biomass of litter in stratum *i* sub-stratum *j* species *k* at monitoring event m_1 in t C
T_L	monitoring interval for litter T_L=m_2-m_1 in years

[19] Smith and Heath, 2002

CF_L carbon fraction of litter, dimensionless

a.5. Soil carbon (C_{SOC})

The soil carbon pool inflows (through plant growth) and outflows (through mineralization) between two monitoring intervals shall be estimated as the difference between the carbon stock estimates of the two consecutive soil monitoring events.

$$\Delta C_{SOC\,ijk,t} = [(C_{SOC_{m2,ijk}} - C_{SOC_{m1,ijk}}) / T_S] \quad \textbf{(M.27)}$$

where:

$\Delta C_{SOC,\,ijk,t}$ annual average change in the carbon stock of soil organic carbon pool in stratum *i* sub-stratum *j* species *k* in t C yr^{-1}.

$C_{SOC,m2,\,ijk,t}$ carbon stock in the soil organic carbon pool in stratum *i* sub-stratum *j* species *k* at monitoring event m_2 in t C

$C_{SOC,m1,\,ijk,t}$ carbon stock in the soil organic carbon pool in stratum *i* sub-stratum *j* species *k* at monitoring event m_1 in t C

T_S time in years between the soil monitoring intervals m_2 and m_1

The carbon stock of soil organic carbon at each monitoring event shall be estimated as per the steps outlined below.

Step 1: The sample plots for soil sampling are selected taking into account the soil type, depth, bulk density in the estimates.

Step 2: Soil organic carbon shall be measured to a depth of 30 cm by collecting soil samples with a soil corer. The samples from the four cores and from the plot center shall be collected.

Step 3: Soil samples collected are aggregated to reduce the variability and sieved through 2 mm sieve, mixed and analyzed in the laboratory.

Step 4: For bulk density analysis, a single core shall be taken next to one of the carbon analysis cores. The samples are oven dried and weighed for bulk density determination and the oven dry weight of the soil samples shall be used to estimate the soil organic carbon.

Step 5: The mass of carbon per unit volume is calculated by multiplying the carbon concentration (percent mass) and bulk density (g/cm^3). The bulk density equals the oven dry weight of the soil core divided by the core volume after discounting the volume of coarse fraction of >2 mm.

$$C_{SOC_{m,ijk,p}} = C_{SOC\_Sample,m,\,ijk,p} \bullet BD_{ijk,p} \bullet Depth_{ijk,p} \bullet FC_{ijk,p} \bullet M \quad \textbf{(M.28)}$$

where:

$C_{SOC,m,\,ijk,p}$ soil organic carbon of plot in stratum *i* sub-stratum *j* species *k* at monitoring event *m* in t C ha^{-1}

$C_{SOC\_Sample,m,ijk,p}$	soil organic carbon of the sample in plot *p* in stratum *i* sub-stratum *j* species *k* determined in laboratory in g C
$BD_{ijk,p}$	bulk density (soil mass/volume of sample) of plot *p* in stratum *i* sub-stratum *j* species *k* determined in laboratory at monitoring event m in t m^{-3}
$Depth_{ijk,p}$	Soil depth at which soil sample is collected in stratum *i* sub-stratum *j* species *k* in cm
$FC_{ijk,p}$	1 – (% volume of coarse fragments/100) to adjust the fraction of sample occupied by coarse fragments > 2mm at plot *p* in stratum *i* sub-stratum *j* species *k* at monitoring event *m*.
M	multiplier to convert units into t C ha^{-1}

Step 6: Calculate the mean carbon soil organic carbon accumulation by pooling the soil carbon estimates of samples at the monitoring interval.

$$MC_{SOC,m,ijk} = \frac{\sum_{p=1}^{P_{ijk}} C_{SOC,m,ijk,p}}{P_{ijk}} \qquad \textbf{(M.29)}$$

where:

$MC_{SOC,m,ijk}$	mean carbon stock in the soil organic carbon pool in stratum *i* sub-stratum *j* species *k* at monitoring event *m* in t C ha^{-1}.
$\Delta C_{SOC,m,ijk,p}$	soil organic carbon of plot *p* in stratum *i* sub-stratum *j* species *k* at monitoring event *m* in t C ha^{-1}
p	plot number in stratum *i*, substratum *j* species *k*
P_{ijk}	number of plots in stratum *i* substratum *j* species *k*

Step 7: Change in soil organic carbon can be estimated by comparing the mean soil organic carbon accumulation between two monitoring periods using the Reliable Minimum Estimate (RME) (Dawkins 1957)[20]. Under the RME approach, the monitoring results of the plots are pooled to assess the mean at monitoring interval m_2 and m_1. The change in soil carbon is calculated by subtracting the maximum estimate of the mean at monitoring time m_1 from the minimum mean estimate at monitoring event m_2. The resulting difference represents the minimum change in the mean soil carbon with 95% confidence between the monitoring interval m_2 and m_1.

$$C_{SOC\,m2,ijk} = [\ MC_{SOC,ijk} - 95\%ConfidenceInterval\ ] \bullet A_{ijk}\,] \qquad \textbf{(M.30)}$$

$$C_{SOC\,m1,ijk} = [\ MC_{SOC,ijk} + 95\%ConfidenceInterval\ ] \bullet A_{ijk}\,] \qquad \textbf{(M.31)}$$

where:

$C_{SOC,m2,ijk}$	soil organic carbon in stratum *i* sub-stratum *j* species *k* at monitoring event m_2 in t C ha^{-1}

[20] Dawkins, H.C. (1957) Some results of stratified random sampling of tropical high forest. Seventh British Commonwealth Forestry Conference 7 (iii) 1-12.

$C_{SOC,m1,ijk}$ soil organic carbon in stratum *i* sub-stratum *j* species *k* at monitoring event m_1 in t C ha^{-1}

This methodology adopts a soil monitoring interval between 10-year and 20-years. The 20-year period is expected to coincide with the crediting period. Shorter monitoring intervals are also allowed.

(b) GHG emissions by sources

The project emissions result from the use of fossil fuels used in carrying out the A/R activities, loss of non-tree biomass in site preparation, biomass burning practices and application of fertilizers.

The increase in GHG emissions resulting from the implementation of A/R CDM project activity should be estimated using the following relationship:

$$GHG_{E,t} = E_{FuelBurn,t} + E_{BiomassLoss,t} + E_{BiomassBurn,t} + E_{N2O\_direct\_N_{fertilizer},t} \quad \textbf{(M.32)}$$

where:

$GHG_{E,t}$ sum of increases in GHG emissions within the project boundary from the implementation of the proposed A/R CDM project activity in t CO_2-eq yr^{-1} in year t

$E_{FuelBurn,t}$ increase in GHG emissions from the burning of fossil fuels within the project boundary in t CO_2eq yr^{-1} in year t

$E_{BiomassLoss,t}$ increase in GHG emissions from the loss of biomass within the project boundary in t CO_2eq yr^{-1} in year t

$E_{BiomassBurn,t}$ increase in GHG emissions from the biomass burning within the project boundary in t CO_2-eq yr^{-1} in year t

$E_{N_2O_{direct-N_{fertilizer},t}}$ increase in N_2O emissions from the application of nitrogenous fertilizers within the project boundary in t CO_2-eq yr^{-1} in year t

b.1. CO_2 emissions from fossil fuels use in the project

Project emissions associated with the use of fossil fuels in A/R project activities such as site preparation, transportation, and silvicultural activities should be calculated taking into account the time of occurrence and the duration of individual activities.

$$E_{FuelBurn,t} = [\, CSP_{diesel,t} \bullet EF_{diesel} + CSP_{gasoline,t} \bullet EF_{gasoline} \,] \bullet 0.001 \quad \textbf{(M.33)}$$

where:

CSP_{diesel} quantity of diesel consumption in litre (l) yr^{-1}. Average annual diesel consumption estimated based on the fuel consumption data of standard operating procedures.

$CSP_{gasoline}$	quantity of gasoline consumption in the project in litre (l) yr^{-1}. Average annual gasoline consumption estimated based on the fuel consumption data of standard operating procedures.
EF_{diesel}	emission factor for diesel in kg CO_2 $liter^{-1}$
$EF_{gasoline}$	emission factor for gasoline in kg CO_2 $liter^{-1}$
0.001	= factor for conversion of kg to tonnes

b.2. Loss of carbon stock in the biomass of non-tree vegetation

It is assumed that some proportion of pre-project non-tree vegetation will disappear during site preparation or competition from planted species. Some vegetation will re-grow even if non-tree vegetation is removed during the site preparation. Therefore, accounting procedure for the initial loss of non-tree biomass is considered transparent.

Step 1: Area associated with the loss of non-tree biomass should be estimated using the sampling methods or estimating the area subjected to site clearance and spacing used in the project A/R activity.

Step 2: Calculate the amount of biomass lost based on the area affected, biomass associated with the area, and the carbon fraction of the biomass.

$$E_{BiomassLoss,i} = \sum_i A_{NT\_BiomassLoss,i} \bullet B_{AB\_NTree\ i} \bullet CF_{NTree} \bullet 44/12 \qquad \forall\ t = 1 \quad \textbf{(M.34)}$$

$$E_{BiomassLoss,t} = 0 \qquad \forall\ t > 1$$

where:

$A_{NT\_Biomass\_Loss,i}$	area of biomass loss in stratum i in ha
$B_{AB\_NTtree,i}$	average biomass stock of non-tree vegetation on land to be planted before the start of a proposed A/R CDM project activity for stratum i in t.d.m. ha^{-1}
CF_{NTree}	carbon fraction of dry biomass in non-tree vegetation in t C $(t.d.m.)^{-1}$, dimensionless
44/12	ratio of moleculrat wights of CO_2 and carbon, dimensionless

b.3. Greenhouse gas emissions from biomass burn

Considering the limited combustible material in degraded lands, fire is not likely to be a major source of GHG emission. However, this methodology takes into account the possibilities of natural fires. Therefore, measures to assess the fire risk should be included, as part of uncertainty analysis and fire control procedures adopted should be outlined in the Project Design Document and Monitoring Plan.

Emissions from fires under this methodology include CO_2 and as well as CH_4 and N_2O. The non-CO_2 GHG emissions result from the incomplete combustion of biomass. The parameters on the GHG emissions from biomass burning should be assessed from local research studies or Good Practice Guidance on LULUCF or the Revised IPCC 1996 Guidelines for LULUCF. The steps to be followed in assessing the GHG emissions from biomass burn include:

Step 1: The area subjected to biomass burning shall be measured and recorded in the monitoring plan.

Step 2: The amount of non-CO_2 emissions is dependent on the loss of carbon in biomass burned. Therefore, CO_2 emissions from biomass burning should be estimated prior to the estimation of non-CO_2 emissions.

$$E_{BiomassBurn,CO_2} = A_{BiomassBurn,i} \bullet B_{AB\_NTree,i} \bullet CE \bullet CF_{NTree} \bullet 44/12 \quad \textbf{(M.35)}$$

where:

$A_{BiomassBurn,i}$	area of biomass burn in stratum *i* in ha yr^{-1}
$B_{AB\_NTree,i}$	average stock in aboveground biomass for stratum *i* prior to burn in t.d.m. ha^{-1}
CE	combustion efficiency, dimensionless, IPCC default =0.5
CF_{NTree}	carbon fraction of dry biomass, dimensionless

Step 3: Suitable combustion efficiencies (Tables 3A.1.12, 3A.1.14 GPG/LULUCF) and emission factors (Tables 3.A 15 and 3.A.16 of GPG-LULUCF) should be used to estimate the emissions of non-CO_2 gases. If national data are not available, mean emission factors for CH_4 (0.012) and N_2O (0.007) that are released from biomass burning should be used.

The *methane (CH_4)* emissions from biomass burn[21]:

$$E_{BiomassBurn,CH_4} = E_{BiomassBurn,CO_2} \bullet GWP_{CH4} \bullet EF_{CH4} \bullet 12/44 \bullet 16/12 \quad \textbf{(M.36)}$$

where:

$E_{BiomassBurn,CH4}$	CH_4 emission from biomass burning in slash and burn in t CO_2eq yr^{-1}
GWP_{CH4}	global warming potential for CH_4 (IPCC default = 21)
EF_{CH4}	emission factor for CH_4, t CH_4 (t C)$^{-1}$ (IPCC default emission ratio for CH_4 = 0.012)
$12/44$	ratio of molecular weights of carbon and CO_2, dimensionless
$16/12$	ratio of molecular weights of CH_4 and carbon, dimensionless

The *nitrous oxide (N_2O)* emissions from biomass burn:

$$E_{BiomassBurn,N_2O} = E_{BiomassBurn,CO_2} \bullet GWP_{N_2O} \bullet (C/N\ ratio) \bullet EF_{N_2O} \bullet 44/28 \bullet 12/44 \quad \textbf{(M.37)}$$

where:

$E_{BiomassBurn,N2O}$	N_2O emission from biomass burning in slash and burn in t CO2eq yr^{-1}
GWP_{N_2O}	global warming potential for N_2O (IPCC default = 310)
$C/N\ Ratio$	carbon-nitrogen ratio, dimensionless
EF_{N_2O}	emission ratio for N_2O, dimensionless (IPCC default factor = 0.0007)

[21] As per Table 5.7,1996 Revised IPCC Guideline for LULUCF and Equation 3.2.19 of GPG LULUCF

$12/44$ ratio of molecular weights of Carbon and CO_2, dimensionless
$44/28$ ratio of molecular weights of N_2O and nitrogen, dimensionless

Step 4: Sum of all non-CO_2 emissions from biomass burning.

$$E_{Non-CO2\_BiomassBurn} = E_{BiomassBurn,N2O} + E_{BiomassBurn,CH4} \quad \textbf{(M.38)}$$

where:

$E_{Non-CO2,\ BiomassBurn}$ increase in Non-CO_2 emission as a result of biomass burning in slash and burn in t CO2eq yr^{-1}

b.4 Estimation of nitrous oxide emissions from fertilization[22]

In situations where fertilizer is used in the project area, the emissions from N_2O should be calculated as per the steps outlined below.

Step 1: Estimate the amount of synthetic and organic fertilizer applied in the project area

$$F_{SN} = N_{SN-Fert} \bullet (1 - Frac_{GASF}) \quad \textbf{(M.39)}$$

$$F_{ON} = N_{ON-Fert} \bullet (1 - Frac_{GASM}) \quad \textbf{(M.40)}$$

where:

F_{SN} = amount of synthetic fertilizer nitrogen applied adjusted for volatilization as NH_3 and NO_X in t N yr^{-1}

F_{ON} = amount of organic fertilizer nitrogen applied adjusted for volatilization as NH_3 and NO_X in t N yr^{-1}

$N_{SN-Fert}$ = amount of synthetic fertilizer nitrogen applied in t N yr^{-1}

N_{SN_Fert} = amount of organic fertilizer nitrogen applied in t N yr^{-1}

$Frac_{GASF}$ = fraction that volatilises as NH_3 and NO_X for synthetic fertilizers, dimensionless

$Frac_{FASM}$ = fraction that volatilises as NH_3 and NO_X for organic manure, dimensionless

When country-specific N_2O emission factors are not available, default emission factor (EF_1) of 1.25 % of applied N should be used. As per 1996 IPCC Guidelines, the default values for the fractions of synthetic fertilizer and organic manure emitted as NO_X and NH3 - 0.1 and 0.2 respectively, should be adopted.

Step 2*:* Calculate nitrous oxide emissions from synthetic and organic fertilizers.

$$N_2O_{direct-N_{fertilizer}} = \left[(F_{SN_t} + F_{ON_t}) \cdot EF_1\right] \bullet GWP_{N_2O} \bullet 44/28 \quad \textbf{(M.41)}$$

where:

[22] Based on Equation 3.2.18 of IPCC GPG-LULUCF

$N_2O_{direct-N_{fertilizer}}$ direct N_2O emissions as a result of nitrogen application within the project boundary in t CO_2-eq yr^{-1}

EF_1 emission factor for emissions from N inputs in t N_2O $(t\ N)^{-1}$

GWP_{N_2O} global warming potential for N_2O (IPCC default = 310)

$44/28$ ratio of molecular weights of N_2O and nitrogen, dimensionless

(c) Actual net GHG removals by sinks

The actual net greenhouse gas removals by sinks represent the sum of verifiable changes in the carbon stocks of pools within the project boundary, minus the increase in GHG emissions measured in CO_2 equivalents by the sources as a result of the implementation of the project activity.

$$\Delta C_{ACTUAL} = \sum_{i=1}\sum_{j=1}\sum_{k=1}\left[\Delta C_{ijk} - GHG_E\right] \qquad \textbf{(M.42)}$$

where:

ΔC_{ACTUAL} = actual net greenhouse gas removals by sinks in t CO2eq yr^{-1}

ΔC_{ijk} = average annual carbon stock change in living biomass of trees for stratum *i* sub-stratum *j* species *k* in t CO_2 yr^{-1}.

GHG_E = GHG emissions by sources within the project boundary as a result of the implementation of an A/R CDM project activity in t CO2eq yr^{-1}

6. Data to be collected and archived for Actual net GHG removals by sinks

Data to be collected or used in order to monitor the verifiable changes in carbon stock in the carbon pools within the project boundary from the proposed A/R CDM project activity, and how this data will be archived:

ID number	Data Variable	Source of data	Data unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Pro-portion of data monitored	Comment
2.1.1.01	Stratum ID	Stratum maps	Alpha-numeric		Prior to the project		Stratification criteria are based on physiographic, soil, climate & vegetation characteristics
2.1.1.02	Sub-stratum ID	Stratum maps	Alpha-numeric		Prior to the project		Criteria relate to the year of planting in each stratum to identify age classes and vegetation characteristics
2.1.1.03	Precision level	Sample frame	%	e	Prior to the project	100%	10% precision level adopted for the purpose of QA/QC
2.1.1.04	Standard deviation of each stratum	Sample frame	Number	e	Prior to the project	100%	To estimate the number of sample plots in each stratum & sub-stratum
2.1.1.05	Sample size	Sample frame	Number	c	Prior to the project	100%	Calculated for each stratum and sub-stratum based on 2.1.1.03 and 2.1.1.04 with equations – M.1 & M.2
2.1.1.06	Plot ID	Plot maps	Alpha-numeric	*c*	Prior to the project	100%	Identified and mapped for each stratum and sub-stratum
2.1.1.07	Plot location	Project and plot maps	Alpha-numeric		5 year	100	Plot location is noted using permanent markets or GPS
2.1.1.08	Age of plantation	Plot data	year	m	5 years	100% sample plots	From the record on the year of project plating

ID number	Data Variable	Source of data	Data unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Pro-portion of data monitored	Comment
2.1.1.09	No. of trees	Plot measurement	Number	m	5 year	Trees in plots	Trees are counted in the plots of each stratum.
2.1.1.10	Diameter at breast height (DBH)	Plot measurement	cm	m	5 years	Trees in sample plots	Measurement of dbh at each monitoring event
2.1.1.11	Mean DBH	Calculated	cm	c	5 years	Trees in sample plots	Calculated using the data on 2.1.1.09 and 2.1.1.10
2.1.1.12	Tree height	Plot measurement	m	m	5 years	100% sample plots	Measured by plot and stratum of the sample frame
2.1.1.13	Mean tree height	Calculated	m	c	5 years	100% sample plots	Calculated based on 2.1.1.09 and 2.1.1.11
2.1.1.14	Merchantable volume	Calculated	m^3	c	5 year	100% sample plots	Calculated using local allometric equations or by using the data on DBH (2.1.1.10) and height (2.1.1.12)
2.1.1.15	Biomass expansion factor (BEF)	Local / national GPG for LULUCF	Ratio	e	5 year	100% sample plots	Locally estimated or collected from the published source
2.1.1.16	Wood density	Local data, GPG for LULUCF	kg/m^3	e	Prior to sampling	100% sample plots	Locally estimated or compiled from local studies, literature, and GPG/LULUCF

ID number	Data Variable	Source of data	Data unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Pro-portion of data monitored	Comment
2.1.11.17	Carbon fraction of above ground tree biomass	IPCC GPG for LULUCF	t C / t.d.m. ha^{-1}	e	Prior to the project monitoring	100% tree species	The tree biomass is multiplied with the default value of 0.5 to convert biomass into carbon.
2.1.1.18	Carbon stock of above- ground tree biomass	Calculated	t C	m	5 years	100% sample plots	Calculated based on 2.1.1.14, 2.1.1.15, 2.1.1.16 & 2.1.1.17
2.1.1.19	Number of non-tree shrub/herb species	Plot survey		e	5 years	100% sample plots	Number of shrub/herb species at each monitoring event are recorded from plot survey to monitor the composition of non-tree vegetation
2.1.1.20	Diameter at the base of shrub	Plot measurement	cm	m	5 years	100% sample plots	Measurement of shrubs in sub-stratum/stratum at each monitoring event
2.1.1.21	Height of shrubs	Plot measurement	m	m	5 years	100% sample plots	Measurement of shrubs in sub-stratum/stratum at each monitoring event
2.1.1.22	Crown diameter of shrubs	Plot measurement	m	m	5 years	100% sample plots	Measurement of shrubs in sub-stratum/stratum at each monitoring event
2.1.1.23	Number of stems in the shrub	Plot measurement	m	m	5 years	100% sample plots	Measurement of shrubs in sub-stratum/stratum at each monitoring event

ID number	Data Variable	Source of data	Data unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Pro-portion of data monitored	Comment
2.1.1.24	Carbon stock of above ground shrub biomass	Calculated	t.d.m. ha^{-1}	m	5 years	100% sample plots	For shrub biomass, available shrub equations are considered and local allometric equations are developed based on 2.1.1.20, 2.1.1.21, 2.1.1.22, and 2.1.1.23, estimated with equation M.16
2.1.1.25	Area under shrubs within the sub-stratum/stratum	Calculated	ha	m	5 years	100% sample plots	Area under shrubs in the sub-stratum/stratum
2.1.1.26	Carbon fraction of shrub biomass	GPG LULUCF	dimensionless	e	Prior to the project monitoring	100% tree species	The tree biomass is multiplied with the default value of 0.5 to convert biomass into carbon.
2.1.1.27	Mean carbon stock of above ground shrub biomass per ha	Calculated	t C	m	5 years	100% sample plots	Calculated based on equation M. 10
2.1.1.28	Above ground herb biomass per ha	Calculated	t C	m	5 years	100% sample plots	Calculated based on equation M. 17
2.1.1.29	Mean carbon stock of above- ground non-tree biomass	Calculated	t C	m	5 years	100% sample plots	Calculated based on equation M.11

ID number	Data Variable	Source of data	Data unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Pro-portion of data monitored	Comment
2.1.1.30	Root-shoot Ratio for tree biomass	Local / National GPG LULUCF	dimensionless	e	5 years	100% sample plots	Local research or published value (Cairns et al 1997).
2.1.1.31	Carbon stock of below-ground tree biomass	GPG LULUCF	t C	e	5 year	100% sample plots	Calculated using root shoot ratio (2.1.1.30) and above ground tree biomass (2.1.1.18)
2.1.1.32	Carbon stock of below ground shrub biomass per ha	Calculated	t C	m	5 years	100% sample plots	Calculated based on equation M.18
2.1.1.33	Root-shoot Ratio for shrub biomass	Local / national GPG for LULUCF	dimensionless	e	5 year	100% sample plots	Local research or published literature
2.1.1.34	Change in the carbon stock of below-ground biomass	Calculated	t C	m	5 years	100% sample plots	Calculated based on equation M.20
2.1.1.35	Standing deadwood	Plot measurements	t C	m	5 years	100% sample plots	It is measured on the lines of live tree measurements.
2.1.1.36	Lying deadwood	Plot measurements	t C	m	5 years	100% sample plots	It is measured using line-intersect method and estimated with equation – M.23 &M.24
2.1.1.37	Total deadwood	Plot measurements	t C	m	5 years	100% sample plots	Calculated based on 2.1.1.35 and 2.1.1.36 with equation – M 20

ID number	Data Variable	Source of data	Data unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Pro-portion of data monitored	Comment
2.1.1.38	Carbon in the litter biomass	Plot measurements	t C	m	5 years	100% sample plots	Litter sampling technique is used and dry weight is taken and samples and M.25 & M.26
2.1.1.39	Soil organic carbon samples in the sub-stratum / stratum	Plot measurement	g.C/100 g soil	m	15-20 years	100% sample plots taken from plots per stratum	Stratified sampling is used to estimate the soil organic carbon using laboratory methods.
2.1.1.40	Bulk density	Plot measurement	100g soil/cm^{-1}	m	15-20 years	100% sample plots	Measured in the stratum /sub-stratum
2.1.1.41	Soil depth	Plot measurement		m	15-20 years	100% sample plots	Measured in the stratum /sub-stratum
2.1.1.42	Area of stratum & sub-stratum	Stratification map and data	ha	m	5 year	100% of strata and sub-strata	Actual area of each stratum and sub-stratum
2.1.1.43	Change in the stock of soil organic carbon in the stratum /-sub-stratum/	calculated	t C	m	15-20 years	100% sample plots	Calculated based on the monitoring data of two soil monitoring events using equation M.27

ID number	Data Variable	Source of data	Data unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Pro-portion of data monitored	Comment
2.1.1.44	Soil organic carbon in the sub-stratum /stratum/species	calculated	t C	m	15-20 years	100% sample plots	Calculated based on the area of sub-stratum/stratum /species and soil organic carbon estimated from sampling using M.28
2.1.1.45	Mean soil organic carbon per ha	calculated	T C ha^{-1}	m	15-20 years	100% sample plots	Calculated based on the plot level soil carbon data using M.29
2.1.1.46	Soil organic carbon with 95% in the mean per ha	calculated	T C	m	15-20 years	100% sample plots	Calculated based on the area of sub-stratum and stratum using equation M.30 and M.31
2.1.1.47	Sum of changes in carbon stocks CO2e	Calculated from plot data	t CO2e	c	5 years	100% Project data	Calculated using the equation M.5

Data to be collected or used in order to monitor the GHG emissions by the sources, measured in units of CO_2 equivalent, that are increased as a result of the implementation of the proposed A/R CDM project activity within the project boundary, and how this data will be archived:

ID number	Data variable	Source of data	Data unit	Measured (m), calculated (c) or estimated (e)	Recording frequency	Proportion of data to be monitored	Comment
2.1.2.01	Diesel / gasoline consumption in A/R activities	On-site Monitoring	Liter	m	Annual	100%	Fuel consumption per unit area for site preparation /harvesting
2.1.2.02	Emission factor for diesel	GPG 2000,	kg/liter	e	At the start of project	100%	National inventory, IPCC default value
2.1.2.03	Emission factor for gasoline	GPG 2000, IPCC Guidelines	kg/liter	e	At the start of project	100%	National inventory, IPCC default value
2.1.2.04	CO_2 emission from fossil fuels	calculated	tCO2e	c	Annual	100%	Calculated using 2.1.2.01, 2.1.2.02, 2.1.2.03, 2.1.2.04 and with equation M.33
2.1.2.13	Area of the burn	Measured	ha	m	Annual	100%	Measured for strata and sub-strata
2.1.2.14	Mean biomass per unit area	Measured before slash and burn	t.d.m. ha^{-1}	m	Annual	100%	Sample survey for strata and sub-strata before the occurrence of biomass burn

ID number	Data variable	Source of data	Data unit	Measured (m), calculated (c) or estimated (e)	Recording frequency	Proportion of data to be monitored	Comment
2.1.2.15	Proportion of biomass burnt	Measured after slash and burn	Ratio	m	Annual	100%	Sampling survey after slash and burn
2.1.2.16	Biomass combustion efficiency	GPG L UL UCF National Inventory	Ratio	e	Prior to the project	100%	IPCC default value (0.5)
2.1.2.17	CO_2 emission from biomass burn	Calculated	t $CO_{2eq\ y}r^{-1}$	c	5 year	100%	Calculated using equation M.35
2.1.2.18	C/N ratio	GPG LULUCF	Ratio	e	Prior to the project	100%	IPCC default value (0.01)
2.1.2.19	N_20 emission From biomass burn	Calculated	t $CO_{2eq\ y}r^{-1}$	c	5 year	100%	Calculated using equation M.36
2.1.2.20	CH_4 emission From biomass burn	Calculated	t CO_{2e} yr^{-1}	c	5 year	100%	Calculated using equation M.37

ID number	Data variable	Source of data	Data unit	Measured (m), calculated (c) or estimated (e)	Recording frequency	Proportion of data to be monitored	Comment
2.1.2.21	Amount of synthetic fertilizer N applied per unit area	Monitoring activity	kg N ha^{-1} yr^{-1}	m	annual	100%	As per the silvicultural and management requirements
2.1.2.22	Amount of organic fertilizer N applied per unit area	Monitoring activity	kg N ha^{-1} yr^{-1}	m	annual	100%	As per the silvicultural and management requirements
2.1.2.23	area of land with N applied	Monitoring activity	Ha yr^{-1}	m	annual	100%	Based on the species and management requirements
2.1.2.24	Amount of synthetic fertilizer N applied	Calculated using equation (20)	t N yr^{-1}	c	annual	100%	Calculated using equation M.39
2.1.2.25	Amount of organic fertilizer N applied	Calculated using equation (21)	t N yr^{-1}	c	annual	100%	Calculated using equation M. 40

ID number	Data variable	Source of data	Data unit	Measured (m), calculated (c) or estimated (e)	Recording frequency	Proportion of data to be monitored	Comment
2.1.2.26	Fraction that volatilises as NH_3 and NO_X for synthetic fertilizers	GPG 2000, GPG LULUCF, IPCC Guideline National inventory	dimensionless	e	Before start of monitoring	100%	IPCC default value (0.1) is used
2.1.2.27	Fraction that volatilises as NH_3 and NO_X for organic fertilizers	GPG 2000, GPG LULUCF, IPCC Guidelines National inventory	dimensionless	e	Before start of monitoring	100%	IPCC default value (0.2) is used
2.1.2.28	Emission factor for emission from N input	GPG 2000, GPG LULUCF, IPCC Guidelines National inventory	N_2O N-input^{-1}	e	Before start of monitoring	100%	IPCC default value (1.25%) is used
2.1.2.29	Direct N_2O emission of N input	Calculated	t CO_2-eq yr^{-1}	c	annually	100%	Calculated using equation M.41

ID number	Data variable	Source of data	Data unit	Measured (m), calculated (c) or estimated (e)	Recording frequency	Proportion of data to be monitored	Comment
2.1.2.30	Total GHG emission from biomass burn	Calculated	t CO_{2e} yr^{-1}	c	5 year	100%	Calculated using equation M.32

7. Leakage

The leakage represents the increase in GHG emissions by sources which occurs outside the boundary of an A/R CDM project activity and which is measurable and attributable to the A/R CDM project activity. Land used for reforestation is degraded and is economical unattractive in comparison to forested land, agricultural land or grazing land, thus, as the result of an A/R CDM project activity, deforestation, agricultural or pastoral activities will not be displaced from the project sites to other locations.

The status of degraded lands and their low productivity do not permit them to support economic alternative uses, however, they continue to support the local uses that were available from them prior to the implementation of the project. As a result, no displacement of economic activities is expected from the implementation of the project. Therefore, in line with the applicability conditions of this methodology displacement of pre-project economic activities to areas outside the project boundary does not occur. The equal treatment of degraded lands in the baseline and project contexts as per the applicability conditions ensures that the costs of monitoring of the goods and services under respective land uses can be avoided in the monitoring.

The major form of leakage under the project is due to the fossil fuel emissions associated with the transportation of personnel and products associated with the project to areas outside the project boundary. Which is calculated from the data collected on the project activities.

(1) Transportation of project personnel and activities to areas outside the project

The fossil fuel combustion from vehicles use due to the transportation of seedling, labours, staff, harvest products, to or from project sites, as a result of the proposed A/R CDM project activity, emits greenhouse gases. This can be monitored and estimated using IPCC bottom-up approach.

The geographically dispersed plots within the project area are expected to contribute to leakage from travel of the staff outside the project boundary. The project activities such as transportation of inputs such as nursery inputs, planting material, labour, staff, and harvested products from the project area emit GHG emissions. These can be monitored and estimated using IPCC default emission factors. The fossil fuel emissions should be estimated based on the numbers of vehicles, distance travelled, fuel consumption, and emission factors.

The data required for the estimation of leakage such as the distance travelled by the project to areas outside the project each year and amount of fossil fuels consumed in the transportation of the project personnel shall be collected from the project monitoring data. The data on the quantity of the thinned wood, distance travelled to the market for the sale of thinned wood, and the quantity of fossil fuels consumed in the travel shall be collected from the project records.

The annual leakage associated with the transportation of project personnel and products to areas outside the project shall be calculated using the steps outlined below.

Step 1: Collecting the travelled distance of different types of vehicles using different fuel types.

Step 2: Determining emission factors for different types of vehicles using different fuel types. Country-specific emission factors shall be developed and used depending on the feasibility. Default emission factors provided in the IPCC Guidelines and updated in the GPG 2000 may be used if there are no locally available data.

Step 3: Estimating the CO_2 emissions using bottom-up approach described in GPG 2000 for energy sector[23].

$$LK_{Vehicle} = \sum_{v}\sum_{f}(EF_{vf} \cdot FuelConsumption_{vf}) \quad \textbf{(M.43)}$$

$$FuelConsumption_{vf} = n_{vf} \cdot k_{vf} \cdot e_{vf} \quad \textbf{(M.44)}$$

[23] Refer to Equation 2.5 and Equation 2.6 in IPCC GPG 2000 for energy sector

where:

$LK_{Vehicle}$	leakage in terms of the CO_2 emissions from fossil fuel combustion in vehicular transportation in t CO_2 yr^{-1}
v	vehicle type
f	fuel type
EF_{vf}	CO_2 emission factor for vehicle type v with fuel type f, dimensionless
$FuelConsumtpion_{vf}$	consumption of fuel type f of vehicle type v, litres
n_{vf}	number of vehicles
k_{vf}	kilometres travelled by vehicle type v i with fuel type f at time t in km
e_{vf}	fuel efficiency of vehicle type v i with fuel type f in litres km^{-1}

8. Data to be collected and archived for leakage

Data and information that will be collected in order to monitor leakage of the proposed A/R CDM project activity:

ID number	Data Variable	Source of data	Data unit	Measured (m) calculated (c) estimated (e)	Recording frequency	Pro-portion of data monitored	Comment
3.1.01	Distance travelled	Project records	Kilometres	e	Annual	100%	Monitoring data on the distance of travel per vehicle type
3.1.02	Number of vehicle types	Project records	Number	m	Annual	100%	Based on the annual project records
3.1.03	Vehicle emission factor (EF)	IPCC	Kg/km	e	Annual	100%	Based on IPCC emission factors
3.1.04	Fuel consumption per km	Local data, national data, IPCC	Litre km^{-1}	e	5 years	100%	Estimated from the monitoring data on the vehicle type and fuel type used
3.1.05	Fuel consumption for road transportation	Project monitoring data	litre	c	Annually	100%	Calculated based on the project monitoring data
3.1.06	Leakage associated with transportation	Project monitoring data	Tonnes CO2e	c	Annually	100%	Calculated using equation M.31

9. Ex post net anthropogenic GHG removal by sinks

Considering that the methodology sets the GHG removals in the baseline scenario to zero for the first and all subsequent monitoring periods, the methodology proposes to calculate the net anthropogenic GHG removals for all monitoring periods as the net GHG removals in the project scenario in that monitoring period.

$$C_{AR-CDM} = \Delta C_{ACTUAL} - \Delta C_{BSL} - LK_{Vehicle} \qquad \textbf{(M.45)}$$

where:

C_{AR-CDM}	net anthropogenic greenhouse gas removals by sinks in t CO_2eq yr^{-1}
ΔC_{ACTUAL}	actual net greenhouse gas removals by sinks in t CO_2eq yr^{-1}
ΔC_{BSL}	baseline net greenhouse gas removals by sinks in t CO_2eq yr^{-1}
$LK_{Vehicle}$	leakage in t CO_2eq yr^{-1}

Calculation of t-CER and l-CERs

The procedures for calculation of t-CERs and l-CERs should follow clarifications regarding methodologies for afforestation and reforestation CDM project activities as offered by Annex 15 to the EB22 report[24].

t-CERs reflect the *existing stock change at the time of verification* minus project emissions minus leakage (t CO_2):

$$t - CER(t_v) = C_P(t_v) - C_B(t_v) - \sum_{0}^{t_v} E_t - \sum_{0}^{t_v} LK_t \qquad \textbf{(M.46)}$$

$$C_P(t_v) - \sum_{0}^{t_v} E_t = \sum_{1}^{t_v} \Delta C_{Actual,\,t} \qquad \textbf{(M.47)}$$

$$C_B(t_v) = \sum_{1}^{t_v} \Delta C_{BSL,\,t} \qquad \textbf{(M.48)}$$

l-CERs reflect the *increment of the stock change* at the time of verification minus project emissions minus leakage compared to the existing stock change at the previous time of verification (t CO_2):

$$l - CER(t_v) = \left[C_P(t_v) - C_P(t_v - \kappa)\right] - \left[C_B(t_v) - C_B(t_v - \kappa)\right] - \sum_{t_{v-\kappa}}^{t_v} E_t - \sum_{t_{v-\kappa}}^{t_v} LK_t \qquad \textbf{(M.49)}$$

$$C_P(t_v) - C_P(t_v - \kappa) - \sum_{t_{v-\kappa}}^{t_v} E_t = \sum_{t_{v-\kappa}}^{t_v} \Delta C_{Actual,\,t} \qquad \textbf{(M.50)}$$

[24] http://cdm.unfccc.int/EB/Meetings/022/eb22_repan15.pdf

$$C_B(t_v) - C_B(t_v - \kappa) = \sum_{t_{v-\kappa}}^{t_v} \Delta C_{BSL,t} \quad \textbf{(M.51)}$$

where:

$tCER(t_v)$	t-CERs issued at year of verification t_v in t CO_2
$lCER(t_v)$	l-CERs issued at year of verification t_v in t CO_2
$C_P(t_v)$	existing carbon stocks at the year of verification t_v in t CO_2
$C_B(t_v)$	estimated carbon stocks of baseline scenario in the year of verification t_v in t CO_2
$E(t)$	annual project emissions in t CO_2
$LK(t)$	annual leakage in t CO_2
t_v	year of verification
κ	time span between two verification occasions in year

10. Uncertainties

(a) Uncertainties to be considered

This methodology uses procedures from IPCC GPG-LULUCF, GPG 2000 and the related rules for A/R CDM project activities to estimate the baseline net GHG removals by sinks, the leakage, the actual net GHG removals by sinks and the net anthropogenic GHG removals by sinks. Potential uncertainties arise from emission factors and sampling surveys. An overview of the types and sources of uncertainties encountered is presented below.

(i) Uncertainties arising from, for example, biomass expansion factors (BEFs) or basic wood density would result in uncertainties in the estimation of both the baseline net GHG removals by sinks and the actual net GHG removals by sinks, especially when global default values are used. This methodology recommends project participants to identify key parameters that would significantly influence the estimation results, and to try to develop local values for key factors using various data sources including direct measurement, or to choose conservative values.

(ii) Uncertainties arising from sample survey (statistical uncertainties): The sampling error for each stratum may result from large spatial variability. Therefore an appropriate sampling protocol is necessary, including sufficient number of samples, variation and uncertainty analysis, sound quality control and quality assurance.

(b) Uncertainty assessment

The percentage uncertainty on the estimate of certain parameters and data (yield table values, biomass expansion factors, wood density, carbon fraction and other biophysical parameters) can be assessed from the sample standard deviation of measured sample values, using half the 95% confidence interval width divided by the estimated value, i.e.[25],

$$U_S(\%) = \frac{\frac{1}{2}(95\% ConfidenceIntervalWidth)}{\mu} \bullet 100 \quad \textbf{(M.52)}$$

[25] Box 5.2.1 in GPG LULUCF

$$= \frac{\frac{1}{2}(4\sigma)}{\mu} \bullet 100 \qquad \textbf{(M.53)}$$

where:

U_S = uncertainty on the estimate of the mean parameter value in percent
μ = sample mean value of the parameter
σ = sample standard deviation of the parameter

If the default parameters are used, uncertainty will be higher than if locally measured parameters are used, and can be only roughly estimated with expert judgment[26].
The percentage uncertainties on quantities that are the product of several terms are then estimated using the following equation[27]:

$$U_S = \sqrt{U_1^2 + U_2^2 + \cdots U_n^2} \qquad \textbf{(M.54)}$$

where:

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

The uncertainty on quantities that are the sum or difference of several terms can be estimated using following simple error propagation equation[28]:

$$U_c = \frac{\sqrt{(U_{s1} \cdot C_{s1})^2 + (U_{s2} \cdot C_{s2})^2 + \cdots + (U_{sn} \cdot C_{sn})^2}}{\left|C_{s1} + C_{s2} + \cdots + C_{sn}\right|} \qquad \textbf{(M.55)}$$

where:

U_c = combined uncertainty in percent
U_{si} = uncertainty on each term of the sum or difference in percent
C_{si} = mean value of each term of the sum or difference

This methodology can reduce uncertainties through:

(i) Proper stratification of the project area into relatively homogeneous strata;
(ii) In setting values for BEFs and root-shoot ratios.
(iii) Non-accounting of the carbon stock increase in the soil organic matter pool that has higher spatial variability than that is observed in the above-ground and below-ground biomass.

Section IV: Lists of variables, acronyms and references

[26] GPG LULUCF Chapter 5.2 and Chapter 3.2
[27] Equation 5.2.1 in GPG LULUCF
[28] Refers to equation 5.2.2 in GPG LULUCF

1. List of variables used in equations:

Parameter	Unit	Description
t	years	Time
m	number	Number of strata
s	number	species type
i	Age (year)	Age classes
n	Number	sample size (number of sample plots required for monitoring)
$t_{\alpha/2}$	dimensionless	value of the statistic t Student, for α = 0.05 (a 95% confidence level)
N_s	Number	total number of strata defined
N_i	Number	number of potential sample units (permanent sample plots) in stratum *I*
N	Number	total number of potential sample units (permanent sample plots)
s_i	Number	standard deviation in stratum *i*
A	percent	permissible error in the mean
C_i	Local currency	cost of selecting a sample plot in stratum *i*
CV^2_1 CV^2_2	dimensionless	coefficient of variation for plots 1 and 2
P_1 P_2	ha	different plot areas and their corresponding
	t	1 to length of crediting period
$\Delta C_{BDL\_ijk,t}$	t CO_2 yr^{-1}	average annual change in the carbon stocks of bare lands or degraded lands with sparse pre-existing vegetation in stratum *i* substratum *j* species *k*
$\Delta C_{BDL\_LB_{ijk,t}}$	t CO_2 yr^{-1}	sum of annual changes in the carbon stocks of living biomass (above- and below-ground) in stratum *i* substratum *j* species *k*
$\Delta C_{BAR,ijk,t}$	t CO_2 yr^{-1}	average annual change in the carbon stocks of pre-project A/R attributable to stratum *i* sub-stratum *j* species *k*
$\Delta C_{BAR\_LB\_Tree_{ijk,t}}$	t CO_2 yr^{-1}	average annual change in the carbon stocks of living tree biomass pools (above-ground and below-ground tree biomass) of the pre-project A/R attributable to stratum *i* sub-stratum *j* species *k*
$\Delta C_{BSL,t}$	t CO_2eq yr^{-1}	baseline net GHG removals by sinks in year *t*
$\Delta C_{ijk,t}$	t CO_2eq yr^{-1}	average annual change in carbon stock in stratum *i* sub-stratum *j* species *k*
$\Delta C_{G,ijk,t}$	t CO_2eq yr^{-1}	average annual growth in carbon *stock* for stratum *i* sub-stratum *j* species *k*
$\Delta C_{L,ijk,t}$	t CO_2eq yr^{-1}	average annual loss in carbon *stock* for stratum *i* sub-stratum *j* species *k*
A_{ijk}	ha	area of stratum *i* sub-stratum *j* species *k*
CF_k	t C $(t.d.m.)^{-1}$	carbon fraction of the biomass for species k
$G_{w,ijk}$	t.d.m. ha^{-1} yr^{-1}	average annual aboveground dry biomass increment of living trees for stratum *i* sub-stratum *j* species *k*
R_{jk}	dimensionless.	root-shoot ratio for species *k* age class *j*
$I_{w,jk}$	m^3 ha^{-1} yr^{-1}	average annual increment in merchantable volume for stratum *i* sub-stratum *j* species *k*
D_k	t.d.m. m^{-3}	basic wood density for species *k*
$BEF_{1,ijk}$	dimensionless	biomass expansion factor for conversion of annual net increment (including bark) in the merchantable volume to total aboveground biomass increment for species *k* age class *j*
$C_{2,LB,ijk}$	t C	carbon stock in the biomass of stratum *i* sub-stratum *j* species *k* calculated at measurement time period 2
$C_{1,LB,ijk}$	t C	carbon stock in the biomass of stratum *i* sub-stratum *j* species *k*, calculated at measurement time period 1
T_B	years	interval in years between measurement periods 2 and 1 to assess the biomass change
$C_{2,LB\_Tree,ijk}$	t C	total carbon stock in living biomass of trees for stratum *i* sub-stratum *j* species *k* calculated at time 2

$C_{1,LB\_Tree,ijk}$	t C	total carbon stock in living biomass of trees for stratum *i* sub-stratum *j* species *k* calculated at time 1
$C_{AB\_Tree,ijk}$	t C	carbon stock in aboveground tree biomass for stratum *i* sub-stratum *j* species *k*
$C_{BB\_Tree,ijk}$	t C	carbon stock in belowground tree biomass for stratum *i* sub-stratum *j* species *k*
V_{ijk}	m^3 ha^{-1}	merchantable volume of stratum i sub-stratum j species k
$BEF_{2,jk}$	dimensionless	biomass expansion factor for conversion of merchantable volume to above-ground tree biomass for age class *j* species *k*
nTR_{ik}	ha^{-1}	number of trees in stratum *i* species *k* in trees
$\Delta C_{SOC,ijk}$	t C	carbon stock in the soil for stratum *i* sub-stratum *j* under species *k* calculated at time 2
$C_{SOC\ 2,ijk}$	t C	annual average change in the carbon stock of soil pool of stratum *i* sub-stratum *j* species *k*
$C_{SOC\ 1,ijk}$	t C	carbon stock in the soil for stratum *i* sub-stratum *j* under species *k* calculated at time 1
T_S	years	interval in years between period 2 and 1 to assess the change in soil organic carbon
$C_{AB,ijk,t2}$	t C	carbon stock in aboveground biomass for stratum *i* sub-stratum *j* species *k* calculated at time t_2
$C_{AB,ijk,t1}$	t C	carbon stock in aboveground biomass for stratum *i* sub-stratum j species *k* calculated at time t_1
$C_{AB\_Tree,ijk}$	t C	carbon stock in aboveground biomass of living trees for stratum *i* substratum *j* species *k*
$C_{AB\_NTree,ijk}$	t C	carbon stock in aboveground biomass of non-tree vegetation for stratum *i* substratum *j* species
$G_{AB\_Stem,ijk}$	t.d.m. ha^{-1}	stem biomass increment in stratum *i* sub-stratum *j* species *k*
$G_{AB\_Branch,ijk}$	t.d.m. ha^{-1}	foliage biomass increment ($G_{AB\_Stem,\ ijk}$ * Ff) in stratum i sub-stratum j species *k*
$G_{AB\_Foliage,ijk}$	t.d.m. ha^{-1}	branch biomass increment ($G_{AB\_Stem,\ ijk}$* Fb) in stratum *i* sub-stratum *j* species *k*
$I_{Tree,ijk}$	m^3 ha^{-1} yr^{-1}	average annual increment of merchantable timber volume for stratum *i* sub-stratum *j* species *k*
$C_{AB\_NTree\_Shrub,ijk}$	t C	carbon stock in aboveground biomass of shrub for stratum *i* substratum *j* species *k*
$C_{AB\_NTree\_Herb,ijk}$	t C	carbon stock in aboveground herb biomass for stratum *i* substratum *j* species *k*
$B_{AB\_NTree\_Shrub,ijk}$	t.d.m. ha^{-1}	above-ground non-tree shrub biomass of woody perennials in stratum *i* sub-stratum *j* (age class of tree) species *k*
D^2_{ijk}	cm	sum of all diameters squared for the woody perennial in stratum *i* sub-stratum *j* (age class of tree) species k
H_i	m	height of the woody perennial from base to its tip in stratum *i* sub-stratum *j* (age class of tree) species *k*
CF_s	t C $(t.d.m.)^{-1}$	carbon fraction for shrub in
A_Shrub,ijk	ha	area of stratum *i* substratum *j* and shrub species *k*
$C_{BB,ijk,t2}$	t C	carbon stock in belowground biomass for stratum *i* sub-stratum *j* species *k* calculated at time t_2
$C_{BB,ijk,t1}$	t C	carbon stock in belowground biomass for stratum i sub-stratum j species *k* calculated at time t_1

$C_{BB\_Tree,ijk}$	t C	carbon stock in belowground biomass of living trees for stratum *i* substratum *j* species k
$C_{AB\_NTree\_Shrub,ijk}$	t C	carbon stock in belowground biomass of non-tree shrubs for stratum *i* substratum *j* species *k*
$C_{BB\_NTree\_Herb,ijk}$	t C	carbon stock in belowground biomass of herb for stratum *i* substratum *j* species *k*
	$R_{T,k,}$	root-shoot ratio of tree species *k*, dimensionless
$C_{BB,ijk}$	t.d.m. ha^{-1}	below-ground biomass of stratum *i* sub-stratum *j* species *k*
$C_{AB\_Stem,ijk}$	t C ha^{-1}	carbon stock of stem biomass of stratum *i* sub-stratum *j* species *k*
$R_{T,k,F}$	dimensionless	root biomass as fraction of stem biomass for species *k*
$R_{S,}$	dimensionless	root-shoot ratio of shrub species *k*
$B_{BB,ijk}$	t.d.m. ha^{-1}	below-ground tree biomass of stratum i sub-stratum j species k
$B_{AB,ijk}$	t.d.m. ha^{-1}	above-ground tree biomass of stratum i sub-stratum j species k
$\Delta C_{DW,ijk}$	t C yr^{-1}	average annual change in the carbon stock of dead wood in stratum *i* sub-stratum *j* species *k*
M_k	dimensionless	average annual rate of natural mortality for species *k*
DC_k	dimensionless	decomposition factor for species *k*
$\Delta C_{SOC,ijk}$	t C. yr^{-1}	average annual carbon stock change in soil organic matter for stratum *i* sub-stratum *j* species *k*
$C_{SOC\_For,ijk}$	t C.ha^{-1}	soil organic carbon stock of afforested/reforested area or forested area that corresponds to the stratum *i* sub-stratum *j* species *k*
$C_{SOC\_Non\_For,i}$	t C.ha^{-1}	soil organic carbon stock of non-forested degraded lands that correspond to the stratum *i* sub-stratum *j* species *k*
$T_{For,ijk}$	years	time period required for transition from SOCNon-For,ij to SOCFor,ijk in years
$C_{SOC\_REF,ijk}$	t C.ha^{-1}	reference soil organic carbon stock under the native unmanaged
f_{ijk}	dimensionless	adjustment factor for the effect of management intensity
$C_{SOCC\_Non\_For,i}$	g C	soil organic carbon content of non-forested degraded land that corresponds to stratum i species k as determined in laboratory
BD_i	g.cm^{-3}	bulk density (soil mass/volume of sample) of non-forested land that corresponds to stratum *i* as determined in laboratory
D_i	cm	soil depth corresponding to stratum *i*
$FC_{,kt}$	dimensionless	1 – (% volume of coarse fragments/100) to adjust the proportion of volume of sample occupied by coarse fragment of > 2mm in stratum *i*
M		multiplier to convert units into t C ha^{-1}
ΔC_{ACTUAL}	t CO_2-eq yr^{-1}	actual net greenhouse gas removals by sinks for year t
$\Delta C,_{ijk.t}$	t CO_2 yr^{-1}	average annual change in carbon pools for stratum *i* sub-stratum *j* species *k* for year t.
GHG_E	t CO_2-eq yr^{-1}	GHG emissions by sources within the project boundary as a result of the implementation of an A/R CDM project activity for year t
$\Delta C_{AB,ijk}$	t C yr^{-1}	average annual changes in carbon stock of aboveground biomass for stratum *i* sub-stratum *j* species *k*
$C_{AB,m2,ijk,t}$	t C	carbon stock of aboveground biomass for stratum *i* sub-stratum *j* species *k* calculated at monitoring event m_2
$C_{AB,m1,ijk,t}$	t C	carbon stock of aboveground biomass for stratum *i* sub-stratum *j* species *k* calculated at monitoring event m_1
$A_{m,ijk}$	ha	area of stratum i sub-stratum j species k at monitoring event m
$MC_{AB,m,ijk}$	t C ha^{-1}	average carbon stock of above ground biomass for stratum *i* sub-stratum *j* species *k* at monitoring event *m*
$MC_{AB\_Tree,m,ijk}$	t C ha^{-1}	average carbon stock of aboveground tree biomass in stratum *i* sub-stratum *j* species *k* at monitoring event *m*
$MC_{AB\_NTree\_Shrub,m,ijk}$	t C ha^{-1}	average annual change in carbon stock of aboveground non-tree shrub

		component in stratum *i* sub-stratum *j* species *k* at monitoring event *m*
$MC_{AB\_NTree\_Herb,m,ijk}$	t C ha^{-1}	average annual change in carbon stock of aboveground non-tree herb component in stratum *i* sub-stratum *j* species *k* at monitoring event *m*
$C_{AB\_Tree,m,ijk,p}$	t C ha^{-1}	plot level above-ground tree carbon stock in stratum *i* substratum *j* species *k* at monitoring event *m*
$MC_{AB\_NTree\_Shrub,m,ijk,p}$	t C ha^{-1}	plot level above-ground non-tree shrub carbon stock in stratum *i* substratum *j* species *k* at monitoring event *m*
$MC_{AB\_NTree\_Herb,m,ijk,p}$	t C ha^{-1}	plot level above-ground non-tree herb carbon stock in stratum *i* substratum *j* species *k* at monitoring event *m*
p	Number	plot number in stratum *i*, substratum *j* species *k*
P_{ijk}	Number	number of plots in stratum *i* substratum *j* species *k*
$C_{AB\_Tree,m,ijk,p}$	t C.ha^{-1}	carbon stock of above-ground tree biomass of stratum i sub-stratum j species k plot p at monitoring event *m*
$C_{AB\_Tree_k}$	t.d.m. ha^{-1}	carbon stock of above-ground tree biomass of species *k*
$f(DBH_k, H_k)$		allometric equation linking merchantable volume to the mean diameter at breast height (DBH) in meters and tree height (H) meters.
C_{AB_Tree,m,k,p_k}	C ha^{-1}	plot level above ground tree carbon stock of stratum *i* sub-stratum *j* species *k* plot *p* at monitoring event *m* in t
XF	dimensionless	expansion factor to represent the per plot value to per ha value
A_p	m^2	Plot area
tr	Number	Tree (TR = total number of trees in the plot)
$C_{AB\_Tree,m,ijk}$	t C.ha^{-1}	carbon stock of above-ground tree biomass of stratum *i* sub-stratum *j* species *k* plot *p* at monitoring event *m*
$V_{Tree,m,ijk}$	m^3.ha^{-1}	merchantable tree volume of stratum *i* sub-stratum *j* species *k* plot *p* at monitoring event *m*
$C_{AB\_NTree\_Shrub,m,ijk,p}$	t C.ha^{-1}	carbon stock of above-ground shrub biomass for tree stratum *i* sub-stratum *j* species *k* plot *p* at monitoring event *m*
CF_{Shrub}	dimensionless	carbon fraction of the above ground shrub biomass
$C_{AB\_NTree\_Herb,ijk,p}$	t C·ha^{-1}	carbon in dry above-ground herb biomass for stratum i substratum j (age class of trees) and tree species *k* for plot *p*
$C_{AB\_NTree\_Herb\_wet,ijk,p}$	g·m^{-2}	carbon in wet above-ground herb biomass for stratum *i* substratum *j* (age class of trees) and tree species *k* for plot *p*
a_{ijk}	m^2	area of sampling frame for stratum *i* substratum *j* (age class of trees) and tree species *k*
MP_{ijk}	dimensionless	weight fraction of moisture in the herb biomass for stratum *i* substratum *j* (age class of trees) and tree species *k* (0 to 1)
$A_{m,ijk}$	ha	area of stratum *i* sub-stratum *j* species *k* at monitoring time *m*
$MC_{BB,m,ijk}$	t C ha^{-1}	average carbon stock of below ground biomass for stratum *i* sub-stratum *j* tree species *k* at monitor time *m*
$R_{T,jk}$	dimensionless	root-shoot ratio for tree species *k* age class *j*
R_S	dimensionless	root-shoot ratio for shrub
R_H	dimensionless	root-shoot ratio for herb
$C_{BB,ijk,t}$	t C. yr^{-1}	average annual carbon stock change in the below-ground biomass in stratum *i* sub-stratum *j* species *k* in year t
$C_{BB,m2,ijk}$	t C	carbon stock of the below-ground biomass for stratum *i* sub-stratum *j* species *k* calculated at monitoring event m_2
$C_{BB,m1,ijk}$	t C	carbon stock of the below-ground biomass for stratum *i* sub-stratum *j* species *k* calculated at monitoring event m_1
$C_{DW,ijk,t}$	t C	average annual change in the biomass of deadwood in stratum *i* sub-stratum *j* species *k* in year t
$C_{DW,m2,ijk}$	t C	carbon stock of deadwood in stratum *i* sub-stratum j species k at monitoring event m_2

$C_{DW,m1,ijk}$	t C	change in the biomass of deadwood in stratum *i* sub-stratum *j* species *k* at monitoring event m_1
T_{DW}	years	monitoring interval for dead wood $T_{DW} = T_B = m_2 - m_1$
$B_{SDW,m,ijk}$	t.d.m.	biomass of standing deadwood in stratum i sub-stratum j species k at monitoring event *m*
$B_{LDW,m,ijk}$	t.d.m.	biomass of lying deadwood in stratum *i,* sub-stratum *j* species *k* at monitoring event *m*
CF_{DW}	dimensionless	carbon fraction of dead wood
$V_{LDW,m,ijk}$	m^3/m^2	volume of lying deadwood in stratum *i* sub-stratum *j* species *k*
$D^2{}_{,ijk}$	m	squared diameter of pieces of dead wood in stratum *i* sub-stratum *j* species *k*
L	m	length of the transect
$B_{LDW,m,ijk}$	t.d.m.	biomass of lying deadwood in stratum *i* sub-stratum *j* species *k* at monitoring event *m*
$D_{DW,dc}$	$kg.d.m/m^3$	basic density of dead wood in the density class – sound (1), intermediate (2), and rotten (3)
$C_{L,m,ijk}$	t C	carbon in dry litter biomass at monitor event *m*
$C_{L,m,ijk}$	t C	carbon in dry litter biomass at monitor event *m*
MP_L	dimensionless	weight fraction of moisture of litter biomass (0 to 1) [(wet weight – dry weight)/wet weight]
a_{ijk}	m^2	area of sampling frame
$\Delta C_{L,m,ijk,t}$	t C yr^{-1}	average annual change in the biomass of litter in stratum i sub-stratum j species k at monitoring event *m*
$C_{L,m2,ijk}$	t C	carbon stock of litter in stratum *i* sub-stratum j species k at monitoring event m_2
$C_{L,m1,ijk}$	t C	change in the biomass of litter in stratum *i* sub-stratum *j species k* at monitoring event m_1
T_L	years	monitoring interval for litter $T_L = m_2 - m_1$
CF_L	dimensionless	carbon fraction of litter
$\Delta C_{SOC,ijk,t}$	t C yr^{-1}	annual average change in the carbon stock of soil organic carbon pool in stratum *i* sub-stratum *j* species *k*
$C_{SOC,m2,ijk,t}$	t C	carbon stock in the soil organic carbon pool in stratum *i* sub-stratum *j* species *k* at monitoring event m_2
$C_{SOC,m1,ijk,t}$	t C	carbon stock in the soil organic carbon pool in stratum *i* sub-stratum *j* species *k* at monitoring event m_1
T_S		time in years between the soil monitoring intervals m_2 and m_1
$C_{SOC,m,ijk,p}$	t C ha^{-1}	soil organic carbon of plot in stratum *i* sub-stratum *j* species *k* at monitoring event *m*
$C_{SOC\_Sample,m,ijk,p}$	g C	soil organic carbon of the sample in plot *p* in stratum *i* sub-stratum *j* species *k* determined in laboratory
$BD_{ijk,p}$	t m^{-3}	bulk density (soil mass/volume of sample) of plot *p* in stratum *i* sub-stratum *j* species *k* determined in laboratory at monitoring event *m*
$Depth_{ijk,p}$	cm	Soil depth at which soil sample is collected in stratum *i* sub-stratum *j* species *k*
$FC_{ijk,p}$		1 – (% volume of coarse fragments/100) to adjust the fraction of sample occupied by coarse fragments > 2mm at plot p in stratum *i* sub-stratum *j* species *k* at monitoring event *m*
M	dimensionless	multiplier to convert units into t C ha^{-1}
$MC_{SOC,m,ijk}$	t C ha^{-1}	mean carbon stock in the soil organic carbon pool in stratum *i* sub-stratum *j* species *k* at monitoring event *m*
$\Delta C_{SOC,m,ijk,p}$	t C ha^{-1}	soil organic carbon of plot *p* in stratum *i* sub-stratum *j* species *k* at monitoring event *m*
p	Number	plot number in stratum *i*, substratum *j* species *k*

P_{ijk}		number of plots in stratum *i* substratum *j* species *k*
$C_{SOC,m2,\,ijk}$	t C ha^{-1}	soil organic carbon in stratum *i* sub-stratum *j* species *k* at monitoring event m_2
$C_{SOC,m1,\,ijk}$	t C ha^{-1}	soil organic carbon in stratum *i* sub-stratum *j* species *k* at monitoring event m_1
$GHG_{E,t}$	t CO_2-eq yr^{-1}	sum of increases in GHG emissions within the project boundary from the implementation of the proposed A/R CDM project activity in year t
$E_{FuelBurn,t}$	t CO_2-eq yr^{-1}	increase in GHG emissions from the burning of fossil fuels within the project boundary in year t
$E_{BiomassLoss,t}$	t CO_2-eq yr^{-1}	increase in GHG emissions from the loss of biomass within the project boundary in year t
$E_{BiomassBurn,t}$	t CO_2-eq yr^{-1}	increase in GHG emissions from the biomass burning within the project boundary in year t
$E_{N_2O_{direct-N_{fertilizer,t}}}$	t CO_2-eq yr^{-1}	increase in N_2O emissions from the application of nitrogenous fertilizers within the project boundary in year t
CSP_{diesel}	litre (l) yr^{-1}	quantity of diesel consumption,.
$CSP_{gasoline}$	litre (l) yr^{-1}	quantity of gasoline consumption in the project.
EF_{diesel}	kg CO_2 liter^{-1}	emission factor for diesel
$EF_{gasoline}$	kg CO_2 liter^{-1}	emission factor for gasoline
0.001	dimensionless	factor for conversion of kg to tonnes
$A_{NT\_Biomass\_Loss}$	ha	area of biomass loss in stratum *i*
$B_{AB\_NTtree,i}$	t.d.m. ha^{-1}	average biomass stock of non-tree vegetation on land to be planted before the start of a proposed A/R CDM project activity for stratum i
CF_{NTree}	t C (t.d.m.)$^{-1}$	carbon fraction of dry biomass in non-tree vegetation
44/12	dimensionless	ratio of molecular weights of CO_2 and carbon,
$A_{BiomassBur\ n,i}$	ha yr-1	area of biomass burn in stratum *i*
$B_{AB\_NTree,i}$	t.d.m. ha^{-1}	average stock in aboveground biomass for stratum *i* prior to burn
CF_{NTree}	t C (t. d. m)$^{-1}$	carbon fraction of dry biomass in non-tree vegetation
CE		combustion efficiency, dimensionless, IPCC default =0.5
$E_{BiomassBurn,CH4}$	t CO_2-eq yr^{-1}	CH_4 emission from biomass burning in slashes and burn
GWP_{CH4}	dimensionless	global warming potential for CH_4
EF_{CH4}	t CH_4 (t C)$^{-1}$	emission factor for CH_4 (IPCC default for CH_4 = 0.012)
$12/44$	dimensionless	ratio of molecular weights of carbon and CO_2
$16/12$	dimensionless	ratio of molecular weights of CH_4 and carbon
$E_{BiomassBurn,N2O}$		N_2O emission from biomass burning in slash and burn in tCO2-eq yr^{-1}
GWP_{N_2O}	dimensionless	global warming potential for N_2O (IPCC default for N_2O = 310)
$C/N\ Ratio$	dimensionless	carbon-nitrogen ratio
$44/28$	dimensionless	ratio of molecular weights of N_2O and nitrogen
EF_{N_2O}	dimensionless	emission ratio for N_2O (IPCC default factor = 0.0007)
$E_{Non-CO2,\ BiomassBurn}$	t CO2eq yr^{-1}	increase in non-CO_2 emission from biomass burning
F_{SN}	t N yr^{-1}	amount of synthetic fertilizer nitrogen applied adjusted for volatilization as NH_3 and NO_X
F_{ON}	t N yr^{-1}	amount of organic fertilizer nitrogen applied adjusted for volatilization as NH_3 and NO_X
$N_{SN-Fert}$	t N yr^{-1}	amount of synthetic fertilizer nitrogen applied

N_{ON_Fert}	t N yr^{-1}	amount of organic fertilizer nitrogen applied
$Frac_{GASF}$	dimensionless	fraction that volatilises as NH_3 and NO_X for synthetic fertilizers
$Frac_{FASM}$	dimensionless	fraction that volatilises as NH_3 and NO_X for organic manure
$N_2O_{direct-N_{fertilizer}}$	t CO_2-eq yr^{-1}	direct N_2O emissions as a result of nitrogen application within the project boundary
EF_1	t N_2O (t N)$^{-1}$	emission factor for emissions from N inputs
ΔC_{ACTUAL}	t CO_2-eq yr^{-1}	actual net greenhouse gas removals by sinks
ΔC_{ijk}	t CO_2 yr^{-1}	average annual carbon stock change in living biomass of trees for stratum i sub-stratum j species k
GHG_E	t CO_2-eq yr^{-1}	GHG emissions by sources within the project boundary as a result of the implementation of an A/R CDM project activity
$LK_{Vehicle}$	t CO_2eq yr^{-1}	CO_2 emissions from fossil fuel combustion in vehicular transportation
v	dimensionless	vehicle type
f	dimensionless	fuel type
EF_{vf}	dimensionless	CO_2 emission factor for vehicle type v with fuel type f
$FuelConssumption_{,vf}$	litres	consumption of fuel type f of vehicle type v
n_{vf}	Number	number of vehicles
k_{vf}	kilometres	kilometres traveled by vehicle type v i with fuel type f at time t
e_{vf}	litres km^{-1}	fuel efficiency of vehicle type v with fuel type f
C_{AR-CDM}	t CO_2eq yr^{-1}	net anthropogenic greenhouse gas removals by sinks
ΔC_{ACTUAL}	t CO_2eq yr^{-1}	actual net greenhouse gas removals by sinks
ΔC_{BSL}	t CO_2-eq yr^{-1}	baseline net greenhouse gas removals by sinks
LK	t CO_2-eq yr^{-1}	leakage
$t\text{-}CER(t_v)$	t CO_2	t-CERs issued at year of verification t_v
$l\text{-}CER(t_v)$	t CO_2	l-CERs issued at year of verification t_v
$C_P(t_v)$	t CO_2	existing carbon stocks at the year of verification t_v
$C_B(t_v)$	t CO_2	estimated carbon stocks of the baseline scenario at year of verification t_v
$E(t)$	t CO_2	annual project emissions
$LK(t)$	t CO_2	annual leakage
t_v	year	year of verification
κ	years	Time span between two verification occasions
U_S	percent	uncertainty on the estimate of the mean parameter value, %
μ		sample mean value of the parameter
σ		sample standard deviation of the parameter
U_S	percent	uncertainty of product (emission by sources or removal by sinks);
U_i	percent	uncertainties associated with each term of the product (parameters and activity data), i=1,2,…,n
U_c	percent	combined percentage uncertainty, %
U_{si}	percent	percentage uncertainty on each term of the sum or difference, %
C_{si}	percent	mean value of each term of the sum or difference

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Appendix I

Use of CO_2FIX Model for E*x-ante* Estimation of Carbon Stock Changes

This methodology permits the use of peer-reviewed model, CO_2FIX for the *ex-ante* estimation of carbon stock changes under the project scenario, provided the model is used in conformity with the methods, steps, and procedures outlined in this methodology. The CO_2FIX model is developed under the carbon sequestration and sustainable forest management (CASFOR) project as an inter-institutional collaboration involving ALTERRA, The Netherlands; The Instituto de Ecologia of University of Mexico in Mexico; The Centro Agronomico Tropical de Investigacion y Ensenanza, (CATIE), Costa Rica; and European Forest Institute, Finland.

The model is available free of charge and the detailed information on CO_2FIX model is available at http://www2.efi.fi/projects/casfor/. The latest version of the model supports investment analysis and calculation of CERs. Description of the model, manual of guidelines for its use, and download instructions are available at the website of European Forest Institute[29].

The CO_2FIX model simulates carbon dynamics and management of single species, multi-species, uneven-aged stands, and agro-forestry systems. It simulates stocks and fluxes of carbon in forest stands on a per hectare basis and at one-year intervals based on growth rates of stem wood available in yield tables and data from field inventories. The basic input in the model is the stem volume growth (from the yield tables or allometric equations or research studies) and parameters on the allocation of volume or biomass to the other tree compartments such as foliage, branches and roots. Carbon stocks in the living biomass are calculated as the balance between growth and loss (from turnover, mortality and harvest).

The CO_2FIX predictions are based on a general model of carbon sequestration and are based on yield models that assume full stocking and a sequence of thinnings over the rotation period. The model uses a cohort approach by specifying cohorts of species or species groups based on their similarity in growth characteristics and parameters. A CO_2FIX file needs to be prepared for each species or species group with supporting parameters. The parameters correspond to the species characteristics in terms of growth, management regime represented through thinning and harvest and variables related to climate, soil, etc. The initial parameters are the initial values of carbon stocks of individual pools at year 0.

Establishing the initial parameters in CO2FIX model

Parameterization is an important step in estimating the carbon stocks. Initial parameters need to be specified for each module. The results from CO_2FIX model should be compared with the field data and further refinement to the parameters should be implemented. The growth of stem biomass (Bs) is expressed as a function of age. The values are initially derived from yield tables and further refined with data from inventories. The biomass allocation coefficients (F) for foliage, branches and roots are expressed as a function of tree age. Like the stem growth rates, the F-parameters have to be refined through destructive sampling. The data used to determine the parameter values are based on scientific and peer reviewed literature. The CO_2FIX model description and its user manual present the data sources and references to research studies on which model parameter is were developed.

[29] http://www2.efi.fi/projects/casfor/downloads/co2fix3_1_description.pdf

The parameterization of the CO_2FIX model is intended to account the variability in carbon stocks through the variables of climate, soil, species characteristics, and management regimes. Since the model relies on the fixed input data from yield tables that are often managed under a silvicultural regime, the yield data parameters adequately represent the stand growth. In addition to stem volume, carbon content of dry matter, and the basic wood density need to be input for each cohort. The parameters related to climate and soils can be selected from the region in which the project is located.

The steps in parameterization of the CO_2FIX model are outlined below.

Step 1: The factors influencing the carbon stocks can be captured using the data and parameters from yield tables, local studies, official publications, peer reviewed literature on vegetation, soil, and climate of the region.

Step 2: It is good practice to assess the mean, median, and range for each parameter required in the CO_2FIX model from the local studies and published literature relevant to the region.

Step 3: Multiple model runs should be done to calibrate the parameters and the model projections shall be compared with the actual data on carbon pools to assess the robustness of the parameters.

Step 4: The CO_2FIX manual should be consulted for implementing the model and for its parameterization[30,31].

Estimation of changes in the carbon stock of tree biomass

Most yield tables report only merchantable stem volume and exclude information on the branch and leaf biomass. In such situations, the CO_2FIX model could be used to estimate the changes in above-ground tree biomass. The steps in this regard are outlined below.

Step 1: The stem volume estimates from yield tables or other studies shall be collected and incorporated under the species files in the CO_2FIX model.

Step 2: The biomass allocation coefficients of foliage (Ff) and branch (Fb) are the functions of age, and used as the parameters in the CO_2FIX model. The biomass allocation coefficients selected should reflect the growth characteristics of the species or species group. The parameters on foliage and branch components can be collected from ecological studies, local research studies, and published literature. The CO_2FIX manual also provides guidance on the sources of data and steps to be followed in the choice of initial parameters to calibrate the model.

$$\Delta C_{AB\_Tree,ijk} = [\, G_{AB\_Stem,ijk} + G_{AB\_Branch,ijk} + G_{AB\_Foliage,ijk} \,] \bullet CF_k$$

where:

[30] Nabuurs, G.J., Garza-Caligaris, J.F., Kanninen, M., Karjalainen, T., Liski, J., Masera, O., Mohren, G.M.J, Pussinen, A., Schelhaas, M.J. 2001. CO2FIX V2.0 - Manual of a model for quantifying carbon sequestration in forest ecosystems and wood products. ALTERRA Report 445. Wageningen, The Netherlands. 48 p

[31] M.J. Schelhaas, P.W. van Esch, T.A. Groen, B.H.J. de Jong, M. Kanninen, J. Liski, O. Masera, G.M.J. Mohren, G.J. Nabuurs, T. Palosuo, L. Pedroni, A. Vallejo, T. Vilén 2004. CO2FIX V3.1 Manual,- description of a model for quantifying carbon sequestration in forest ecosystems and wood products. ALTERRA Report 1068. Wageningen, The Netherlands.

$\Delta C_{AB\_Tree,\ ijk}$ above-ground tree biomass increment in stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1}

$G_{AB\_Stem,\ ijk}$ stem biomass increment in stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1}

$G_{AB\_Branch,\ ijk}$ foliage biomass increment ($G_{AB\_Stem,\ ijk}$ * Ff) in stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1}

$G_{AB\_Foliage,\ ijk}$ branch biomass increment ($G_{AB\_Stem,\ ijk}$* Fb) in stratum i sub-stratum j species *k* in t.d.m. ha^{-1}

CF_k carbon fraction for species k, dimensionless

Note: the variable age class is reflected in sub-stratum *j*

Step 3: The model projections should be compared with the biomass estimates from available studies on similar species types or data from secondary studies and published literature in order to demonstrate the validity of the parameters and to improve the robustness of the model projections.

Step 4: The projections of CO_2FIX model are in the time steps of 1 year and follow the gain-loss approach, which takes into account growth and loss of tree biomass during the year from harvest and disturbances such as fire, pest etc. The annual change in the tree carbon stock is reflected in the *ex-ante* estimation. The growth parameters reflect the annual increases and losses of above-ground tree biomass are reflected in thinning, harvests and disturbance.

$$\Delta C_{AB\_Tree,ijk} = A_{ijk} \bullet \sum_i \sum_j \sum_k \left(\Delta C_{AB\_Tree\_Growth,ijk} - \Delta C_{AB\_Tree\_Loss,ijk} \right)$$

where:

$\Delta C_{AB\_Tree,\ ijk}$ annual change in the above-ground tree biomass in stratum *i* sub-stratum *j* species *k* in t C

$\Delta C_{AB\_Tree\_Growth,\ ijk}$ annual growth in tree biomass in stratum *i*, sub-stratum *j* species *k* in t C. ha^{-1}

$\Delta C_{AB\_Tree\_Loss,\ ijk}$ annual loss in tree biomass in stratum *i* sub-stratum *j* species *k* in t C. ha^{-1}

A_{ijk} area of stratum *i* substratum *j* and species *k* in ha

The harvested biomass from thinning and harvest is subtracted from the existing biomass, and the slash and deadwood from the harvests are added to the soil module since these are expected to get decomposed over time.

$$\Delta C_{AB\_Tree\_Loss,ijk} = \Delta C_{AB\_Tree\_Harvest,ijk} + \Delta C_{AB\_Tree\_Dist,ijk} \ )$$

$\Delta C_{AB\_Tree\_Harvest,\ ijk}$ annual change in the loss of tree biomass from harvest in stratum *i* sub-stratum *j* species k in t.d.m. ha^{-1} yr^{-1}

$\Delta C_{AB\_Tree\_Dist,\ ijk}$ annual change in the loss of tree biomass from disturbance in stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1} yr^{-1}

Estimation of carbon stock changes in non-tree shrub biomass

The shrub biomass can be estimated by modelling the non-tree woody perennial species as a cohort of species *k*. The data on shrubs can be collected from local studies or published literature and used to parameterize the shrub growth in the model to estimate the shrub biomass and its projected carbon stock change.

Estimation of carbon stock changes in below-ground biomass

In the CO_2FIX model, the relation between below-ground biomass and above-ground biomass is expressed as follows.

$$C_{BB_{ijk}} = [C_{AB\_Stem_{ijk}} \bullet R_{T,kF}]$$

where:

$C_{BB,ijk}$ = below-ground biomass of stratum *i* sub-stratum *j* species *k* in t.d.m. ha^{-1}

$C_{AB\_Stem,ijk}$ = carbon stock of stem biomass of stratum *i* sub-stratum *j* species *k* in t C ha^{-1}

$R_{T,k,F}$ = root biomass as fraction of stem biomass for species *k*, dimensionless

Estimation of carbon stock changes in deadwood

In the CO_2FIX model, deadwood is included in coarse woody litter (stems and stumps) and, to a lesser extent in the short fine woody litter (fine and coarse branches, coarse roots). The data on natural mortality found in the literature and research studies and yield tables can be used to parameterize the mortality variable as a fraction of the standing biomass in the **Biomass** main menu under **Mortality** tab. The mortality can be grouped into natural mortality and mortality due to management activities and can be represented as a fraction of the standing biomass. This fraction can vary with age or with the ratio between actual and maximum attainable biomass.

Mortality is estimated as a function of tree age or as a function of relative biomass (ratio of standing biomass to maximum stand biomass). In addition to tree mortality carbon dynamics in other biomass compartments need to consider the turnover of foliage, branches, and roots of the remaining trees.

Thinning and harvests can increase mortality depending on harvest methods and technology used and can be expressed in terms of number of trees, basal area, volume, or thinned or harvested biomass. The model also takes into account the decomposition fraction in modelling deadwood component.

Estimation of carbon stock changes in litter

The data on litter estimates from literature shall be used to parameterize the CO_2FIX model. Data on litter can be either directly input into the model or can be estimated using the biomass module through biomass turnover, natural mortality, management mortality, and logging slash.

Estimation of changes in soil organic carbon

CO_2FIX uses Yasso model[32] to model soil carbon dynamics. The Yasso model describes decomposition and dynamics of soil carbon and calibrates the total stock of the soil carbon without distinction between soil layers. It uses parameters from soil module, deadwood and litter parameters from the biomass module, and climate parameter inputs under the General parameters tab. The root

[32] See Liski et al http://www.efi.fi/projects/yasso/

compartment is distinguished into coarse root and fine root at the time of turnover. The fractions of these two are assumed to follow the ratio between branches and foliage litter. Since turnover of fine roots is higher, total root turnover is higher under short rotation species than under long rotation ones.

The soil module consists of two tabs - General parameters and Cohort parameters. The parameters for the soil module are used under the Soil main menu. In the General parameters tab, the user needs to provide climate parameters for the site. These are effective temperature sum (degree days above zero) over the year (°C d), precipitation (mm), and potential evapo-transpiration (mm). The model has been tested to evaluate the effects of climate on decomposition rates of litter in a wide range of ecosystems (Liski et al. 2003, Palosuo et al. 2003).

The data on soil organic carbon estimates shall be used from literature to parameterize the CO_2FIX model. It uses non-woody litter (foliage and fine roots), fine woody litter (branches and coarse roots) and coarse woody litter (stems and stumps) as components that undergo decomposition over time. The fractionation of litter determines the rate of decomposition in each time step and is influenced by climate variables such as temperature and moisture.

Assessment of uncertainty in CO_2FIX model

The CO_2FIX model has simulation algorithms to assess the uncertainty. The parameters of the model take into account the variability of growth rates in species, carbon content, and humus decomposition, and multiple runs capture the uncertainty in the carbon pools. Since the annual increment data from yield tables are based on sample plot data that are based on valid inventory procedures, the scenario analysis of CO_2FIX model can be considered robust in assessing the variability. The over or underestimation of actual net GHG removals can be minimized by correct identification of the site class of lands and by using the yield models that closely represent the site quality and species growth rates under the project scenario.

Transparency and conservativeness of ex-ante estimates

The CO_2FIX model usually makes conservative estimation of carbon stocks in the above-ground biomass and litter. It also provides inputs to soil module. All data used in CO_2FIX model are based on valid scientific research, forest inventory and management methods. The ex-ante estimates of CO_2FIX model are conservative in comparison to values calculated from the field data. Therefore, it is reasonable to use CO_2FIX model for *ex-ante* estimation of the actual net GHG removal by sinks under the project.