Draft A/R Methodological tool

"Estimation of emissions from clearing, burning and decay of existing vegetation due to implementation of a CDM A/R project activity"

(Version 01)

I. SCOPE, APPLICABILITY, ASSUMPTIONS AND PARAMETERS

Scope

1. This tool can be used to estimate the increase in emissions of greenhouse gases due to vegetation existing within the project boundary at the time an A/R project commences—the "existing vegetation"—being cleared, burned, or left to decay as part of site preparation or other project implementation activities[1].

2. The tool provides:

- Guidance on conditions under which emissions can be considered insignificant, and need not be accounted (Section II).
- Two methodological procedures to estimate emissions attributable to site preparation, that may be used individually or in combination:
  - A simplified default approach for estimating emissions from existing vegetation as a result of site preparation (Section III). The approach assumes all emissions occur at the time of site preparation as a result of a single site preparation practice.
  - A generalised approach for estimating emissions from existing vegetation when more complex site preparation practices are used (Section IIII). The approach also allows for time-dependent accounting of emissions from the gradual decay of dead woody biomass, if required.

3. The tool also includes an Annex that provides:

- Guidelines and guidance on selecting IPCC default data for estimating emissions due to site preparation.
- Guidelines for conservative choice of default data used to estimate the above- and below-ground biomass of existing vegetation.
- Guidelines on estimating biomass stocks by field measurement. These guidelines can be used to determine biomass data (including provision of root:shoot ratios) when suitable default data are either not available, or must be confirmed as applicable. The guidelines may also be referenced as a source of generalised stand-alone methodology for estimation of above- and below-ground biomass stocks.

Applicability

4. The tool is applicable for estimating the increase in project emissions resulting from the clearance, burning and decay of existing vegetation due to site preparation and project implementation practices within the CDM A/R project boundary:

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[1] The term "site preparation" as used henceforth in this document includes all activities associated with establishment of forest (or other planted vegetation) by the A/R project activity that result in emissions from existing vegetation, whether such activities are specifically mentioned or not. Such activities include clearance of existing vegetation by felling or fire, decay of felled or burned existing vegetation, and decay of existing vegetation that dies as a result of competition from forest (or other vegetation) planted as part of A/R project activities.

- **Increase in CO_2 emissions**—project emissions may occur either as a result of clearance of existing live vegetation during site preparation (including by slash-and-burn practices) within the project boundary, and/or from decay of un-cleared existing live vegetation that dies as a result of competition from forest (or other vegetation) planted as part of the A/R project activity.
- **Increase in emissions of non-CO_2 greenhouse gases**—project emissions will occur when existing live and dead above-ground vegetation within the project boundary is either partially or totally burned as part of site preparation[2], resulting in emissions of methane (CH_4) and nitrous oxide (N_2O)—although N_2O emissions are an insignificant proportion of total emissions from biomass burning and so need not be accounted.

5. If this tool is used as part of an A/R project methodology, the following applicability conditions shall be added to the methodology, as required[3]:

- If the use of fire for site preparation is not specifically excluded, then add the following applicability condition:
  - If fire is used during site preparation then measures such as installation of fire-breaks or back-burning shall be taken to ensure fire does not spread outside the project boundary: that is, no leakage emissions from biomass burning shall be permitted to occur due to site preparation activities.
- If the use of fire for site preparation is not specifically excluded, but the dead organic matter pools are accounted, then add the following applicability condition to implicitly account for non-CO_2 emissions due to fire[4]:
  - If fire is used during site preparation, increase by 10% the value of biomass estimated for the dead organic matter pools at the time the project commences. This implicitly accounts for CH_4 emissions from biomass burning, which then need not be separately accounted.
- Calculation of emissions can be simplified, and project emissions reduced, if trees existing at the time the project commences are not removed or damaged as part of site preparation. If emissions from removal of existing tree biomass are not to be accounted, add the following applicability condition:
  - Site preparation shall be restricted to clearance of non-tree vegetation, with any biomass burning (if applicable) carried out in such a way as to avoid damage to existing trees within the project boundary.

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[2] Note that CO_2 emissions from burning of existing live vegetation are always accounted under applicability item (i). CO_2 emissions from existing dead vegetation would have occurred in the absence of the project, and so need not be accounted.

[3] If any of the applicability conditions listed under A–D are required, then project proponents must also provide suitable monitoring methodology to prove the applicability conditions are met. It is expected that photographic evidence (possibly including images from aircraft or satellites) would be suitable for proving adherence to applicability conditions under items A and B. Compliance with the applicability condition under item C can be demonstrated by requiring site preparation to be consistent with the conditions in the *Procedure to determine when accounting of the soil organic carbon pool may be conservatively neglected in CDM A/R project activities*; EB33 Meeting Report, Annex 15.

[4] If the existing dead organic matter pools are not accounted, both CO_2 and non-CO_2 emissions from the dead organic matter pools may be conservatively neglected as it is expected that existing biomass stocks in these pools will be considerably smaller than in the project scenario. On the other hand, if the pools are accounted, CO_2 emissions will be explicitly taken into account, and the only extra accounting required is of CH_4 emissions if burning occurs.

- Unless changes in the soil carbon pool are explicitly accounted, add the following applicability condition to ensure site preparation activities do not result either in significant emissions from oxidation of soil carbon or in significant accountable losses due to erosion:
    - Site preparation shall be carried out in such a way that no significant losses of soil carbon occur due to soil disturbance or erosion3.

Assumptions

6. The following assumptions are made in developing this tool:

- When fire is used as part of site preparation, all existing vegetation biomass remaining after fire is assumed to be dead—whether felled as part of site preparation or not.
- Rates of decay of felled un-burned woody biomass, and of woody biomass left after burning, are the same. A constant rate of decay is assumed for woody biomass, consistent with IPCC default approaches.

Parameters

7. This tool provides procedures to determine the following parameters:

Parameter	SI Unit	Description
$E_{BiomassLoss}$	t CO_2	Increase in CO_2 emissions from loss of existing biomass due to site-preparation (including burning), and/or to competition from vegetation attributable to the CDM-A/R project activity.
$E_{BiomassBurn}$	t CO_2-e	Increase in non-CO_2 emissions due to biomass burning as part of site preparation.

Conventions Used in this Tool

8. In developing this methodological tool, biomass loss is determined separately for the tree, shrub, and herbaceous vegetation classes. This is because these classes will usually have similar within-class—but very different between-class—values of mean biomass, decay time, and combustion properties. Separating the emissions estimates by class is therefore expected to make calculations both simpler and more transparent.

9. Although distinguishing between herbaceous vegetation and woody perennial shrubs presents few problems, there is no universal definition that uniquely distinguishes shrubs from smaller trees. If both smaller trees and shrubs are part of existing vegetation, then a practical working definition to distinguish these vegetation classes under field conditions shall be developed, and recorded in the CDM-AR-PDD as part of forest inventory standard operating procedures. Any such definition should be consistent with common practice in the region or country in which the project exists, and shall be applied uniformly to both existing vegetation, and vegetation established as part of A/R project implementation.

II. GUIDANCE ON CONDITIONS UNDER WHICH EMISSIONS FROM EXISTING VEGETATION DUE TO SITE PREPARATION NEED NOT BE ACCOUNTED

10. Emissions from felling, clearance, decay or burning of existing biomass during site preparation need not be accounted if at least one of the conditions (i) to (iii) below are met:

(i) If it can be demonstrated that fire due to natural or anthropogenic causes is a common occurrence in the baseline scenario, and:

- Such fire has affected all vegetation within the proposed project area[5] at least once in the last 10 years; and;
- The baseline vegetation is not a fire-adapted ecosystem.

(ii) If it can be demonstrated that due to natural or anthropogenic causes other than fire, felling of all vegetation in the project area[5] is a common occurrence in the baseline scenario, and also that such clearance has occurred at least once within the proposed project area in the last 10 years.

(iii) The baseline scenario is *degrading land* involving decline in woody vegetation cover at a rate such that complete loss of woody vegetation is expected within the proposed project area[5] over 20 years.

11. Demonstrating that particular natural or anthropogenic causes are a common occurrence can be performed by:

(i) Either; providing documented evidence that “slash-and-burn” or similar land clearance activities are commonly practiced in the region on land areas that represent the baseline scenario, and that vegetation within the proposed project boundary is:

- Already typical of that commonly cleared by “slash-and-burn” or similar land clearance activities; or
- In the absence of the project would within 10 years of the proposed start of the project become typical of vegetation commonly cleared by “slash-and-burn” or similar land clearance activities.

(ii) Or; providing evidence from published studies, official reports, or analysis of land-use change that demonstrates that fire or felling is a common occurrence as part of the baseline land use for land areas including the project area[6], and:

- Due to natural or anthropogenic causes fire or felling has caused the loss of all woody species at least once within the proposed project boundary within the 10 years prior to project commencement; and
- Climatic, vegetative cover, legal, policy, and regulatory circumstances under which fire or felling of woody species occurred in the past are expected either to remain unchanged in the future, or to change in such a way as to make removal of woody species more likely than in the past.

III. METHODOLOGICAL PROCEDURE: A SIMPLIFIED DEFAULT APPROACH TO ESTIMATION OF EMISSIONS DUE TO SITE PREPARATION

12. Site preparation for a CDM A/R project activity may involve the partial or total clearance (including by burning) of existing vegetation as a result of site preparation. Alternatively, competition from forest or other vegetation established as part of A/R project activities can result in the death and decay of existing vegetation. These losses of existing biomass are treated as an increase in emissions within the project boundary. In general, emissions from loss of existing biomass will occur as two components: immediate emissions of CO_2 and non-CO_2 from biomass burning if slash-and-burn practices are used, and emissions of CO_2 over a period of months to decades from decay of remaining burned and/or unburned vegetation.

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[5] Emissions may be neglected at the project, parcel, or individual stratum level, as applicable, depending on the extent of the area likely to be affected.

[6] If studies are not available that include all or part of the project area, studies on land areas with characteristics similar to the proposed project area may be used. Such studies must have been performed for lands with similar existing vegetation, climate, topography, altitude, and soils. The lands must also be subject to the same legal, policy and regulatory frameworks as the proposed project area.

13. To provide a simplified approach to estimation of CO_2 and non-CO_2 emissions associated with site preparation, the following assumptions are made[7]:

- All existing vegetation is considered to be instantaneously oxidised at the time of site preparation.
- If fire is used as part of site preparation the area burned shall be defined as a stratum, and all biomass in the stratum is considered to be burned.
- If other site preparation methods are used the area cleared/felled shall be defined as a stratum, and all vegetation in the stratum is considered to be cleared/felled.
- The following values from IPCC literature can be used as defaults for the carbon fraction of the tree, shrub and herbaceous vegetation classes, respectively (see Annex 1): 0.50, 0.49, 0.47 t C $(t\ d.m.)^{-1}$.
- The following conservative default factors derived from IPCC literature can be used for the fraction of biomass left to decay after burning (f_{BL}) in the tree, shrub and herbaceous vegetation classes, respectively (see Annex 1): 0.4, 0.05, 0.0 t d.m. $(t\ d.m.)^{-1}$. That is, a conservative estimate of the amount of biomass burned and which generates non-CO_2 emissions is equal to $1 - f_{BL}$.

Under the instant oxidation assumption, the CO_2 emissions for each stratum are given by:

$$E_{BiomassLoss} = \left(L_{SP,tree} + L_{SP,shrub} + L_{SP,herb}\right) \,{}^{44}\!/_{12} \qquad \textbf{(1)}$$

and:

$$L_{SP,tree} = A_S\ B_{AB,tree}\left(1 + R_{tree}\right)\ CF_{tree} \qquad \textbf{(2)}$$

$$L_{SP,shrub} = A_S\ B_{AB,shrub}\left(1 + R_{shrub}\right)\ CF_{shrub} \qquad \textbf{(3)}$$

$$L_{SP,herb} = A_S\ B_{AB,herb}\left(1 + R_{herb}\right)\ CF_{herb} \qquad \textbf{(4)}$$

where:

$E_{BiomassLoss}$	Increase in CO_2 emissions from loss of biomass in existing vegetation as a result of site preparation; $t\ CO_2$
L_{SP}	Carbon stock loss in existing tree, shrub or herbaceous vegetation (as indicated by subscripts in equations) as a result of site preparation; *t C*
A_S	Area of the stratum; *ha*
B_{AB}	Average above-ground biomass stock of tree, shrub or herbaceous vegetation (as indicated by subscripts in equations); $t\ d.m.\ ha^{-1}$
R	Average root:shoot ratio appropriate for biomass stocks, for tree, shrub or herbaceous vegetation (as indicated by subscripts in equations); $t\ d.m.\ ha^{-1}\ (t\ d.m.\ ha^{-1})^{-1}$.
CF	Average carbon fraction of biomass for tree, shrub or herbaceous vegetation (as indicated by subscripts in equations); $t\ C\ (t\ d.m.)^{-1}$. IPCC default values for tree, shrub and herbaceous vegetation, respectively, are: 0.50, 0.49, 0.47
${}^{44}\!/_{12}$	Conversion factor: ratio of molecular weights of CO_2 and C; $mol\ mol^{-1}$

[7] The Methodological Procedure in Section III may be used if these assumptions are too restrictive.

14. If fire is used for site preparation, in addition to the CO_2 emissions estimated using equations (1) to (4) it is necessary to also estimate the instantaneous non-CO_2 emissions due to biomass burning. These are calculated as the fraction of above-ground biomass burned times the CH_4 emission ratio for biomass burning, and adjusted to CO_2 equivalents. For each stratum:

$$E_{BiomassBurn} = \left(L_{SP,\,fire,tree} + L_{SP,\,fire,shrub} + L_{SP,\,fire,herb}\right) ER_{CH4} \ {}^{16}\!/_{12} \ GWP_{CH4} \qquad \textbf{(5)}$$

and:

$$L_{SP,\,fire,tree} = A_S \ B_{AB,tree} \left(1 - f_{BL,tree}\right) \ CF_{tree} \qquad \textbf{(6)}$$

$$L_{SP,\,fire,shrub} = A_S \ B_{AB,shrub} \left(1 - f_{BL,shrub}\right) \ CF_{shrub} \qquad \textbf{(7)}$$

$$L_{SP,\,fire,herb} = A_S \ B_{AB,herb} \left(1 - f_{BL,herb}\right) \ CF_{herb} \qquad \textbf{(8)}$$

where:

$E_{BiomassBurn}$	Increase in non-CO_2 greenhouse gas emissions as a result of biomass burning; *t CO_2-e*
$L_{SP,\,fire}$	Carbon stock loss from burning of existing tree, shrub or herbaceous vegetation (as indicated by subscripts in equations) during site preparation; *t C*
ER_{CH4}	Emission ratio for CH_4 (IPCC default: 0.012)[8]; *kg C as CH_4 (kg C burned)$^{-1}$*
GWP_{CH4}	Global warming potential for CH_4 (IPCC default: 21 for the first commitment period); *t CO_2-e (t CH_4)$^{-1}$*
A_S	Area of the stratum; *ha*
B_{AB}	Average above-ground biomass stock of existing tree, shrub or herbaceous vegetation (as indicated by subscripts in equations); *t d.m. ha^{-1}*
f_{BL}	Average fraction of existing above-ground tree, shrub or herbaceous biomass (as indicated by subscripts in equations) left to decay after biomass burning; dimensionless. Default values derived from IPCC literature for trees, shrub and herbaceous vegetation, respectively, are: 0.4, 0.05, 0.0
CF	Average carbon fraction of biomass for trees, shrub or herbaceous vegetation (as indicated by subscripts in equations); *t C (t d.m.)$^{-1}$*. IPCC default values for tree, shrub and herbaceous vegetation, respectively, are: 0.50, 0.49, 0.47
${}^{16}\!/_{12}$	Conversion factor: ratio of molecular weights of CH_4 and C; *mol mol^{-1}*

15. Use of equations (2)–(4) and (6)–(8) for estimation of carbon stock losses requires values for the following parameters for each of the tree, shrub and herbaceous vegetation classes: the average above-ground biomass[9], and the average root:shoot ratio, by stratum. Values for these parameters may be obtained by conservative choice of default data from IPCC literature, national inventory, or published peer-reviewed studies. Alternatively, values may be obtained by direct field measurement. Annex 1 identifies suitable default data in IPCC literature for above-ground biomass and root:shoot

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[8] Table 3A.1.15, Annex 3A.1, *GPG-LULUCF* (IPCC 2003)

[9] Lands within the project area may have a verifiable history of periodic clearance of existing vegetation by fire or felling, but at a frequency lower than that which enables emissions to be neglected under Section I. In this case, estimation of emissions due to site preparation may be based on the average levels of biomass present over multiple fire/felling cycles. If this is to be done, transparent and verifiable information must be provided to support conservative choice of the average levels of biomass selected.

ratios, and provides guidance on conservative choice of such data. The Annex also provides methodology that may be used for direct measurement of above-ground biomass and root:shoot ratios, if required.

IV. METHODOLOGICAL PROCEDURE: A GENERALISED APPROACH TO ESTIMATION OF EMISSIONS DUE TO SITE PREPARATION

16. In this section a more generalised approach is given for estimation of emissions associated with site preparation. It allows for partial clearance/felling of vegetation within a stratum (e.g., because forest is only being established in strips to allow silvopastoral activities, or to avoid erosion), and for biomass burning to be used for all or only part of the cleared area. Provision is also included for time-dependent accounting of emissions from decay of vegetation, since woody material can take several decades (or longer) to decompose. As well as being more realistic, accounting for the time dependence of emissions also avoids having all liabilities from such emissions occur at the start of the project.

Estimation of CO_2 emissions due to loss of biomass in existing vegetation

17. In general, CO_2 emissions from loss of existing biomass[9] during site preparation will occur as two components: immediate CO_2 emissions from biomass burning if this is used, and emissions over a period of months to decades from decay of remaining burned and/or un-burned vegetation that is felled. Existing un-felled vegetation[10] is also likely to die and decay in those areas in which forest is established as part of A/R project activities, due to competition. Thus, for each stratum:

$$E_{BiomassLoss,t} = \left(L_{SP,fire,t} + L_{SP,decay,t}\right) {}^{44}\!/_{12} \qquad \textbf{(9)}$$

where:

$E_{BiomassLoss,t}$	Annual CO_2 emissions from loss of biomass in existing vegetation in year t as a result of site preparation, and/or implementation of A/R project activities, at time $t = t_{sp}$; $t\ CO_2\ yr^{-1}$
$L_{SP,fire,t}$	Annual carbon stock loss in year t from burning of existing vegetation biomass during site preparation; $t\ C\ yr^{-1}$
$L_{SP,decay,t}$	Annual carbon stock loss in year t from decay of existing vegetation as a result of site preparation; $t\ C\ yr^{-1}$
t	Years elapsed since the start of the project; $0, 1, 2 \ldots n_t$
${}^{44}\!/_{12}$	Conversion factor: ratio of molecular weights of CO_2 and C; $mol\ mol^{-1}$

18. When estimating the two carbon stock loss components required for eqn. (9), the following possible circumstances need to be considered:

(i) If biomass burning is used as part of site preparation, the fraction of above-ground biomass left after burning, f_{BL}, will depend on factors such as climate, the type of vegetation present, and fire intensity. However, values of f_{BL} are not usually specified in terms of these parameters, and so conservative average default values should be chosen (as discussed in Annex 1).

[10] Whether this affects also large trees existing at the time of project implementation will depend on whether such trees are protect during any burning as part of site preparation, and/or on whether trees are felled. In general, when estimating existing biomass stocks relevant for use in equations in this tool, always consider carefully which biomass classes (and components within classes) will be affected by the site preparation activities described in the CDM-AR-PDD.

(ii) For simplicity in developing the equations that follow, any above-ground biomass remaining after fire is assumed to be dead, and together with all below-ground biomass in the burned area is assumed to decay completely over the single time period T_{decay}.

(iii) The planted area within the project boundary may be either larger, or smaller, than the area burned as part of site preparation. If larger, CO_2 emissions will still occur in the area planted but not burned, either because vegetation is felled or because it dies due to competition from vegetation established as part of A/R project activities. Both above- and below-ground biomass in any area planted but not burned is assumed to decay completely over a time period T_{decay}.

19. Taking the above into account, and denoting the time at which site preparation occurs by t_{SP}, the annual carbon stock loss due to site preparation by biomass burning within a given stratum can be estimated as:

If $t \neq t_{SP}$ then $L_{SP,fire,t} = 0$, otherwise:

$$L_{SP,\,fire,t} = A_S \; f_{SP,\,fire} \; L_{AB,\,fire,t} \qquad \textbf{(10)}$$

where:

$L_{SP,\,fire,\,t}$	Annual carbon stock loss in year t from burning of existing vegetation biomass during site preparation; $t\ C\ yr^{-1}$
A_S	Area of the stratum; *ha*
$f_{SP,\,fire}$	Fraction[11] of the stratum subject to biomass burning during site preparation in year $t = t_{SP}$; dimensionless
$L_{AB,\,fire,\,t}$	Annual carbon stock loss per unit area in existing above-ground vegetation in year $t = t_{SP}$ from biomass burning; $t\ C\ ha^{-1}\ yr^{-1}$
t	Years elapsed since the start of the project; $0, 1, 2 \ldots. n_t$

20. If $f_{planting}$ is the fraction of the stratum to be planted as part of implementation of A/R project activities, general expressions for the annual loss in carbon stock due to decay of vegetation—that take into account emissions from decay of biomass left after burning, if applicable—are for a stratum given by:

If $t < t_{SP}$, or $t > (t_{SP} + T_{decay})$, then $L_{SP,\,decay,\,t} = 0$.

Otherwise, if $f_{planting} > f_{SP,\,fire}$ then:

$$L_{SP,decay,t} = A_S \; f_{SP,\,fire} \; L_{AB,BL,decay,t} + A_S \; (f_{planting} - f_{SP,\,fire}) \; L_{AB,decay,t} + A_S \; f_{planting} \; L_{BB,decay,t} \qquad \textbf{(11)}$$

Or if $f_{planting} \leq f_{SP,\,fire}$, then:

$$L_{SP,decay,t} = A_S \; f_{SP,\,fire} \; L_{AB,BL,decay,t} + A_S \; f_{SP,\,fire} \; L_{BB,decay,t} \qquad \textbf{(12)}$$

where:

$L_{SP,decay,t}$	Annual carbon stock loss in year t from decay of existing vegetation as a result of site preparation (including burning) and/or implementation of A/R project activities at time $t = tsp$; $t\ C\ yr^{-1}$
A_S	Area of the stratum; *ha*

[11] If the biomass is collected into piles or rows before burning, the appropriate value for $f_{SP,\,fire}$ is the fraction of the stratum area over which collection occurs.

$f_{SP, fire}$	Fraction[11] of the stratum subject to biomass burning during site preparation at $t = t_{SP}$; dimensionless
$L_{AB, BL, decay, t}$	Annual carbon stock loss per unit area in year t from decay of existing above-ground biomass left after burning during site preparation at $t = t_{SP}$; $t\ C\ ha^{-1}\ yr^{-1}$
$f_{planting}$	Fraction of the stratum planted as part of the A/R project activity; dimensionless
$L_{AB, decay, t}$	Annual carbon stock loss per unit area in year t from decay of existing un-burned above-ground biomass due to clearance/felling and/or implementation of A/R project activities; $t\ C\ ha^{-1}\ yr^{-1}$
$L_{BB, decay, t}$	Annual carbon stock loss per unit area in year t from decay of existing below-ground biomass as a result of site preparation (including by burning) and/or implementation of A/R project activities; $t\ C\ ha^{-1}\ yr^{-1}$
t	Years elapsed since the start of the project; $0, 1, 2 \ldots n_t$, where $t_{SP} \leq t \leq (t_{SP} + T_{decay})$

21. The first term in eqn. (11) represents losses in above-ground biomass left to decay after burning during site preparation; the second term represents losses in un-burned areas due to clearance of existing vegetation or competition from forest (or other vegetation) established during implementation of the A/R project activity, and the third term represents losses in below-ground biomass in any area subject to site preparation and/or project implementation activities.

22. If fire is not used as part of site preparation, eqn. (11) reduces to the simpler form required to account only for emissions from decay of vegetation:

$$L_{SP,decay,t} = A_S\ f_{planting}\ L_{B,\ decay,t} \qquad \textbf{(13)}$$

where:

$L_{SP,decay,t}$	Annual carbon stock loss in year t from decay of existing vegetation as a result of site preparation; $t\ C\ yr^{-1}$
A_S	Area of the stratum; *ha*
$f_{planting}$	Fraction of the stratum planted as part of the A/R project activity; dimensionless
$L_{B, decay, t}$	Annual carbon stock loss per unit area in year t from decay of existing above- and below-ground biomass (in un-burned areas) as a result of site preparation; $t\ C\ ha^{-1}\ yr^{-1}$
t	Years elapsed since the start of the project; 0, 1, 2 …. n_t, where $t_{SP} \leq t \leq (t_{SP} + T_{decay})$

Estimation of non-CO_2 emissions

23. As noted in Section II of the tool, the only significant non-CO_2 emissions associated with biomass burning are due to release of methane (CH_4). If t_{SP} is the time at which site preparation occurs, non-CO_2 emissions for a stratum are given by:

If $t \neq t_{SP}$ then $E_{BiomassBurn} = 0$, otherwise:

$$E_{BiomassBurn,t} = E_{BiomassBurn,CH_4,t} \qquad \textbf{(14)}$$

where:

$E_{BiomassBurn, t}$	Annual increase in non-CO_2 greenhouse gas emissions at time $t = t_{SP}$ as a

	result of biomass burning; $t\ CO_2\text{-}e\ yr^{-1}$
$E_{BiomassBurn,\ CH4,\ t}$	Increase in CH_4 emissions at time $t = t_{SP}$ as a result of biomass burning; $t\ CO_2\text{-}e\ yr^{-1}$
t	Years elapsed since the start of the project; 0, 1, 2 …. n_t

24. Estimation of CH_4 emissions is based on the annual carbon stock loss from biomass burning during site preparation, $L_{SP,\ fire,\ t}$, calculated using eqn. (10). This is multiplied by factors that adjust for the mass of CH_4 versus carbon released, and for the global warming potential of CH_4. Thus, for each stratum:

$$E_{BiomassBurn,CH_4,t} = L_{SP,\ fire,t}\ ER_{CH4}\ \ {}^{16}\!/_{12}\ \ GWP_{CH4} \qquad \textbf{(15)}$$

where:

$E_{BiomassBurn,\ CH4,\ t}$	Increase in CH_4 emissions at time $t = t_{SP}$ as a result of biomass burning; $t\ CO_2\text{-}e\ yr^{-1}$
$L_{SP,\ fire,\ t}$	Annual carbon stock loss in year t from burning of existing vegetation biomass during site preparation; $t\ C\ yr^{-1}$
$ER_{\ CH4}$	Emission ratio for CH_4 (use IPCC default value, 0.012)[12]; $kg\ C\ as\ \ CH_4\ (kg\ C\ burned)^{-1}$
GWP_{CH_4}	Global warming potential for CH_4 (IPCC default: 21 for the first commitment period); $t\ CO_2\text{-}e\ (t\ CH_4)^{-1}$
${}^{16}\!/_{12}$	Ratio of molecular weights of CH_4 and C; $mol\ mol^{-1}$

$L_{SP,\ fire,\ t}$ is determined from eqn. (10). This in turn requires estimation of $L_{AB,\ fire,\ t}$, which together with estimation of other carbon stock loss components is discussed in the next section below.

Estimation of carbon stock losses due to biomass burning and decay

25. The carbon stock loss components $L_{AB,\ fire}$, $L_{AB,\ decay}$, $L_{AB,\ decay,\ BL}$, $L_{BB,\ decay}$ and $L_{B,\ decay}$ required by equations (10)–(13) are estimated from the biomass stock in the relevant pool(s)—divided by the time over which a particular pool decays for those components accounting for losses due to biomass decay[13].

26. As noted in Section II, accounting by vegetation class is recommended for simplicity and transparency. Depending on the stratification scheme adopted by a project, strata may contain either single or multiple vegetation classes (i.e. one or more of trees, shrubs and herbaceous vegetation), and single or multiple species within each vegetation class. The general forms of the equations for estimating the carbon stock loss components by vegetation class, and by species within each class, are given below. In these equations the tree, shrub and herbaceous vegetation classes are represented by the sub-scripted variable *VC,* which takes a value of 1, 2 and 3 for trees, shrubs and herbaceous vegetation, respectively. For each stratum:

$$L_{AB,\ fire,t} = \sum_{VC=1}^{3} \sum_{j=1}^{n_S} B_{AB,VC,\ j} \left(1 - f_{BL,VC}\right) CF_{VC} \qquad \textbf{(16)}$$

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[12] Table 3A.1.15, Annex 3A.1, *GPG-LULUCF* (IPCC 2003)

[13] If, for simplicity, time-independent accounting is preferred, set T_{decay} = 1 for all vegetation classes.

$$L_{AB,decay,t} = \sum_{VC=1}^{3} \sum_{j=1}^{n_S} B_{AB,VC,j}\ CF_{VC}\ \Big/\ T_{decay,j} \qquad \textbf{(17)}$$

$$L_{AB,decay,BL,t} = \sum_{VC=1}^{3} \sum_{j=1}^{n_S} B_{AB,VC,j}\ f_{BL,VC}\ CF_{VC} \Big/ T_{decay,j} \qquad \textbf{(18)}$$

$$L_{BB,decay,t} = \sum_{VC=1}^{3} \sum_{j=1}^{n_S} B_{BB,VC,j}\ CF_{VC} \Big/ T_{decay,j} \qquad \textbf{(19)}$$

$$L_{B,decay,t} = \sum_{VC=1}^{3} \sum_{j=1}^{n_S} (B_{AB,VC,j} + B_{BB,VC,j})\ CF_{VC} \Big/ T_{decay,j} \qquad \textbf{(20)}$$

where:

$L_{AB,\ fire\ t}$	Annual carbon stock loss per unit area at time $t = t_{SP}$ as a result of biomass burning; $t\ C\ ha^{-1}\ yr^{-1}$
$B_{AB,\ VC,\ j}$	Existing above-ground biomass per unit area in the tree, shrub or herbaceous vegetation class *VC*, by individual species *j* within a class; $t\ d.m.\ ha^{-1}$
CF_{VC}	Average carbon fraction of biomass in the tree, shrub or herbaceous vegetation class *VC*; $kg\ C\ (kg\ d.m.)^{-1}$. IPCC default values for tree, shrub and herbaceous vegetation, respectively, are (see Annex 1): 0.50, 0.49, 0.47.
$f_{BL,\ VC}$	Average fraction of existing above-ground biomass left to decay after biomass burning, in the tree, shrub and herbaceous vegetation class *VC*; dimensionless. Default values derived from IPCC literature for trees, shrub and herbaceous vegetation, respectively, are (see Annex 1): 0.4, 0.05, 0.0
$L_{AB,decay,\ t}$	Annual carbon stock loss per unit area in year *t* from decay of existing un-burned above-ground biomass due to site preparation; $t\ C\ ha^{-1}\ yr^{-1}$
$T_{decay,\ j}$	Time for existing vegetation species *j* to decay completely; *yrs*
$L_{AB,\ decay,\ BL,\ t}$	Annual carbon stock loss per unit area in year *t* from decay of existing above-ground biomass left after burning during site preparation at $t = t_{SP}$; $t\ C\ ha^{-1}\ yr^{-1}$
$L_{BB,\ decay,\ t}$	Annual carbon stock loss per unit area in year *t* from decay of existing below-ground biomass as a result of site preparation (including by burning); $t\ C\ ha^{-1}\ yr^{-1}$
$B_{BB,\ VC,\ j}$	Existing below-ground biomass per unit area in the tree, shrub or herbaceous vegetation class *VC,* by individual species *j* within a class; $t\ d.m.\ ha^{-1}$
$L_{B,\ decay,\ t}$	Annual carbon stock loss per unit area in year *t* from decay of above- and below-ground biomass due to site preparation, in the tree, shrub or herbaceous vegetation class *VC,* as applicable; $t\ C\ ha^{-1}\ yr^{-1}$
VC	Vegetation class; 1, 2, and 3 denotes trees, shrubs and herbaceous vegetation, respectively, as applicable.
j	Number of species within a vegetation class; $1, 2 \ldots n_s$
t	Years elapsed since the start of the project; $0, 1, 2 \ldots n_t$, where $t_{SP} \leq t \leq (t_{SP} + T_{decay})$

If, as will usually be the case, values of below-ground biomass are not available, they should be estimated using appropriate values of the root-shoot ratio:

$$BB_{VC,j} = AB_{VC,j}\ R_{VC,j} \qquad \textbf{(21)}$$

where:

$B_{BB,\,VC,\,j}$	Below-ground biomass of species *j* in vegetation class *VC*; *t d.m. ha*$^{-1}$
$B_{AB,\,VC,\,j}$	Above-ground biomass of species *j* in vegetation class *VC*; *t d.m. ha*$^{-1}$
$R_{VC,\,j}$	Root:shoot ratio of species *j* in vegetation class *VC*; *kg d.m. (kg d.m.)*$^{-1}$
VC	Vegetation class; 1, 2, and 3 denotes trees, shrubs and herbaceous vegetation, respectively.
j	Number of species within a vegetation class; *1, 2 ….* n_s

27. The fraction of existing above-ground biomass left to decay after burning, f_{BL}, depends on the methods used for site preparation, as well as on the combustion properties of the burned vegetation—which in turn depend mainly on the vegetation type, climate, time since felling, and fire intensity. However, values of f_{BL} are not usually available as a function of these variables, so conservative choice of values to cover the range of circumstances is required. Moreover, this parameter does not usually have a large effect on either the magnitude or timing of overall emissions, unless it is unusually large. It is therefore recommended that default values of f_{BL} derived from IPCC literature be used whenever possible. Generic values derived from IPCC literature were given for trees, shrubs and herbaceous vegetation as part of the variable definition for f_{BL} (see Annex 1 for further details, including for sources of default species-specific data). Alternatively, values of f_{BL} from national inventory reports or peer-reviewed published studies may be used as default values if these match project circumstances more precisely. Values of all data should be chosen conservatively, according to the guidelines in Annex 1.

28. The time period over which vegetation decays, T_{decay}, depends primarily on whether the vegetation involved is herbaceous, or woody. Herbaceous vegetation (including leaves of woody species) decays rapidly, whereas woody material such as logs may take several decades—or longer—to completely decompose. If values for T_{decay} are not available from national inventory reports, or from peer-reviewed published studies, IPCC default values can be used. For herbaceous vegetation, the IPCC default assumption is that decay occurs instantaneously (instant oxidation; IPCC 2003)), which is equivalent to setting $T_{decay} = 1$. For woody material, the IPCC default is for a constant rate of decay over a period of 20 years (i.e. $T_{decay} = 20$; IPCC 2003). If the vegetation of interest is not strongly dominated by the biomass of either woody or leaf (herbaceous) material—as may occur with shrubs for example—then an average decay time should be used, calculated as the default decay time for woody material times the ratio of woody to total biomass[14]. A default value of 10 years (i.e. $T_{decay} = 10$) may be used for shrubs if no better data are available.

29. Use of equations (16)–(21) for estimation of carbon stock losses also requires values for two parameters for at least each of the tree, shrub and herbaceous vegetation classes, and for species within a class (if available), by stratum: the average above- and below-ground biomass. Further, estimation of below-ground biomass will usually require values for the root:shoot ratio. Values for these parameters may be obtained by conservative choice of default data from IPCC literature, national inventory, or published peer-reviewed studies. Alternatively, values may be obtained by direct field measurement. Annex 1 identifies suitable default data in IPCC literature for above-ground biomass and root:shoot ratios, and provides guidance on conservative choice of such data. The Annex also provides methodology that may be used for direct measurement of above-ground biomass and root:shoot ratios, if required.

[14] This is also likely to result in a more appropriate value of T_{decay} for below-ground biomass, as species with a higher leaf-to-woody biomass ratio will tend also to have a higher ratio of fine-to-coarse roots—and both leaf and fine root biomass decay rapidly.

References

IPCC 2003. *Good Practice Guidance for Land Use, Land-use Change and Forestry*. This is available from the IPCC Secretariat (www.ipcc.ch), or may be downloaded from the National Greenhouse Gas Inventory Programme at http://www.ipcc-nggip.iges.or.jp.

IPCC 2006. *Guidelines for National Greenhouse Gas Inventory. Volume 4; Agriculture, Forestry and Other Land*. Available from the IPCC Secretariat (www.ipcc.ch), or downloadable from the National Greenhouse Gas Inventory Programme at http://www.ipcc-nggip.iges.or.jp.

Annex 1

DEFAULT DATA AND MEASUREMENT METHODOLOGY FOR ESTIMATION OF CARBON AND BIOMASS STOCKS IN EXISTING VEGETATION

1. This Annex provides guidelines and guidance on the following topics:

- Guidelines and guidance on selecting IPCC default data for estimating emissions due to site preparation (Section A.I).
- Guidelines for conservative choice of default data used to estimate above- and below-ground biomass of existing vegetation (Section A.II).
- Guidelines on estimating biomass stocks by field measurement (Section A.III). These guidelines can be used to determine biomass data (including provision of root:shoot ratios) when suitable default data are either not available, or must be confirmed as applicable. The guidelines may also be referenced as a source of generalised stand-alone methodology for estimation of above- and below-ground biomass stocks.

A.I. GUIDELINES AND GUIDANCE ON SELECTING IPCC DEFAULT DATA FOR ESTIMATING EMISSIONS DUE TO SITE PREPARATION

A.I.1. IPCC default data for the carbon fraction of biomass

2. Default values of 0.50 and 0.47 t C $(t\ d.m.)^{-1}$, for the carbon fraction of trees and herbaceous vegetation respectively, are given in the Good Practice Guidance for Land Use, Land-use Change and Forestry (abbreviated as *GPG-LULUCF*)[15], or in the Guidelines for National Greenhouse Gas Inventory, Chapter 4, Agriculture, Forestry and Other Land (abbreviated as *AFOLU Guidelines*)[16]. For shrubs a value of 0.49 may be used, as the mean for tree and herbaceous vegetation—given most shrubs will have similar amounts of woody and foliage biomass.

A.I.2. IPCC default data for above-ground biomass in existing vegetation

3. IPCC default data for the above-ground biomass of vegetation existing at the time an CDM A/R project commences (the "existing vegetation") may be obtained from the *GPG-LULUCF* (IPCC 2003) and *AFOLU Guidelines* (IPCC 2006), as follows:

- ***Tree above-ground biomass:*** values should be selected from data given for natural forests in Tables 4.7 and 4.12 of the *AFOLU Guidelines* (IPCC 2006), or from Tables 3A.1.2 and 3A.1.4 of the *GPG-LULUCF* (IPCC 2003). Depending on the species present, data in Tables 4.8 and 4.12 of the *AFOLU Guidelines* (IPCC 2006), or from Tables 3A.1.3 of the *GPG-LULUCF* (IPCC 2003), may also be relevant. Data shall be chosen according to the location, climate zone and species group, as applicable, that most closely matches the project's circumstances. Note that these values apply to continuous cover forest. Thus, multiply values obtained by the fraction of tree crown cover in the baseline stratum of interest, to obtain values of existing above-ground biomass relevant to the project.
- ***Shrub above-ground biomass:*** IPCC literature includes values of natural shrubland above-ground biomass for only one case—tropical shrubland by continental location, in Table 4.7 of the *AFOLU Guidelines* (IPCC 2006). The values given are about 30% of average biomass

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[15] Good Practice Guidance for Land Use, Land-use Change and Forestry, Chapter 3, Section 3.2.1.1.1.1. IPCC 2003. Available from the IPCC Secretariat (www.ipcc.ch), or downloadable from the National Greenhouse Gas Inventory Programme at http://www.ipcc-nggip.iges.or.jp.

[16] Guidelines for National Greenhouse Gas Inventory. Volume 4; Agriculture, Forestry and Other Land; Chapter 6, Section 6.3.1.4. IPCC 2006. Available from the IPCC Secretariat (www.ipcc.ch), or downloadable from the National Greenhouse Gas Inventory Programme at http://www.ipcc-nggip.iges.or.jp

values for forest in the same location. If no better default data relevant to the project are available from national inventory reports or published peer-reviewed studies, select a value of shrub biomass equal to 30% of the value appropriate for tree above-ground biomass for the project. These values apply to continuous cover shrubland. Thus, multiply values obtained by the fraction of shrub crown cover in the baseline stratum of interest, to obtain values of above-ground biomass relevant to the project.

- ***Herbaceous above-ground biomass:*** values should be selected from Table 3.4.2 of the *GPG-LULUCF* (IPCC 2003) or Table 6.4 of the *AFOLU Guidelines* (IPCC 2006), by choosing a climate zone that most closely matches the project circumstances. Note that values of above-ground biomass referred to in the Tables are peak values, and should be reduced according to project circumstances, as follows:
  - If lands within the project boundary are grazed, or degraded, halve the value selected.
  - If lands are both grazed and degraded, take one quarter of the value selected.
  - The values chosen apply to a continuous herbaceous cover. Thus, complete the parameter estimation by multiplying values obtained by the fraction of herbaceous ground cover in the baseline stratum of interest, to obtain values of above-ground biomass relevant to the project.

A.I.3. IPCC default data for root:shoot ratios

4. IPCC default data for the root:shoot ratio of vegetation existing at the time an CDM A/R project commences may be obtained from the *GPG-LULUCF* (IPCC 2003) and *AFOLU Guidelines* (IPCC 2006), as follows:

- ***Tree root:shoot ratio:*** values should be selected from Table 3A.1.8 of the *GPG-LULUCF* (IPCC 2003), or equivalently Table 4.4 of the AFOLU Guidelines (IPCC 2006), by choosing a climatic zone and species that most closely matches the project circumstances. Alternatively, given that many datasets of root:shoot ratios are relatively small because of the difficulty of determining this parameter, conservative selection of a value about one standard deviation (c. 0.04) above the mean (0.26) found in the global study by Cairns *et al.* (1997) is likely to provide a reliable conservative default value. A value of 0.3 kg d.m. (kg d.m.)$^{-1}$ may thus be used as a generic root:shoot ratio for all trees.
- ***Shrub root:shoot ratio:*** IPCC literature includes shrubland root:shoot ratios for only one case—a value of 0.4 for tropical shrublands, in Table 4.4 of the *AFOLU Guidelines* (IPCC 2006). This value is about 1.25 times that of tree root:shoot ratios for tropical forests, and similar to 1.25 times the value recommended above for all trees from the study of Cairns *et al.* (1997) If no better default data relevant to the project are available from national inventory reports or published peer-reviewed studies, 0.4 may be used as a generic root:shoot ratio for all shrubland.
- ***Herbaceous root:shoot ratio:*** values should be selected from Table 3.4.3 of the *GPG-LULUCF* (IPCC 2003) or equivalently from Table 6.1 of the *AFOLU Guidelines* (IPCC 2006), by choosing a climate zone that most closely matches the project circumstances. Values of the root:shoot ratio selected may need to be adjusted for use in eqn. (4) because grazing activities that reduce above-ground herbaceous biomass do not usually reduce below-ground biomass. Use of unadjusted values of the root:shoot ratio could therefore result in an under-estimate emissions associated with site clearance. Assuming adjustments to above-ground biomass for grazing and/or degradation have been made as detailed above in this section, make also the following adjustments to the root:shoot ratio:
  - If lands within the proposed project boundary are non-degraded and grazed, double the value from Tables 3.4.3 or 6.1.
  - If lands are degraded, halve the value selected from Tables 3.4.3 or 6.1.

- If lands are both grazed and degraded, use the value from Tables 3.4.3 or 6.1 without further modification.

A.I.4. IPCC default data for the fraction of above-ground biomass left after fire

5. The fraction of existing above-ground biomass left to decay after burning, f_{BL}, depends on the methods used for site preparation, as well as on the combustion properties of the burned vegetation—which in turn depend mainly on the vegetation type, climate, time since felling, and fire intensity. However, values of f_{BL} are not usually available as a function of these variables, so conservative choice of values to cover the range of circumstances is required. Moreover, values of f_{BL} do not have a large effect on total emissions from biomass burning as they effect directly[17] only the estimation of non-CO_2 emissions, which account for about 10% of total emissions from site preparation activities. It is thus unlikely to be cost effective to put effort into developing accurate project-specific factors.

6. Some species-specific default values can be obtained from Table 3A.1.12 and Table 2.6 of the *GPG-LULUCF* (IPCC 2003) and *AFOLU Guidelines* (IPCC 2006), respectively. These can also be used to develop conservative default data by vegetation class. The following conservative values for f_{BL} have been calculated from the IPCC data, as approximately one standard deviation above mean values for data for trees, shrubs and herbaceous vegetation, respectively: 0.4, 0.05, 0.0 t d.m. $(t\ d.m.)^{-1}$.

A.II. GUIDELINES FOR CONSERVATIVE CHOICE OF DEFAULT DATA USED TO ESTIMATE ABOVE-AND BELOW-GROUND BIOMASS OF EXISING VEGETATION

7. Default data may be obtained from IPCC literature, national greenhouse gas inventory, or peer-reviewed publications and reports. When using such data for estimation of emissions associated with site preparation, the guidelines below should be followed in order to avoid over-estimation of net anthropogenic removals by sinks:

(i) If default data are available for conditions that are similar to the project (same vegetation *genus*[18]; same climate zone; similar soil fertility and water holding capacity), then mean values of default data may be used and are considered conservative.

(ii) In all other circumstances, if mean values of default data are to be used, the applicability of the mean values must be established through verification against field measurements (see Section A.III for details). This includes, as appropriate, verification of the applicability of mean data from default allometric equations by destructive harvesting. Default data may be considered valid if the measured data fall within ±10% of the mean default value—and provided that if any bias is evident it results in a conservative estimate of project net anthropogenic removals by sinks.

(iii) When project circumstances are not similar to those for which default data exist, or if the applicability of mean values of default data is not to be verified by field measurement, conservative values of default data shall be selected. These are defined as being approximately one standard deviation above mean values. Values can be selected by:

- If standard deviations are quoted then use these directly, or if a standard error is quoted then calculate the standard deviation by multiplying the standard error by the square root of the number of samples.
- If a range of data is quoted, but without a standard deviation being given, then assume the range represents the upper and lower 95% limits of a normally distributed dataset.

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[17] The value of f_{BL} also has a secondary effect on the ratio of immediate to time-dependent CO_2 emissions, if time dependent accounting is used. However, considered over the lifetime of the project, this affects only the timing and not the magnitude of CO_2 emissions.

[18] See, for example, http://www.treecanada.ca/trees/genus.php?sort=en_genus&lang=en

In this case the appropriate conservative value is that which falls half way between the mean and the upper limit of the range.

- If only mean data are quoted, assume the following nominal values for standard deviations (as estimated from the range in IPCC data for these parameters—see *Section A.I.3* for detailed references), expressed here as percentages of the mean:
  - Above-ground biomass of existing vegetation: trees (50%), shrubs (50%), herbaceous vegetation (40%);
  - Root:shoot ratios for use in estimation of below-ground biomass: for trees—35% if using other than the generic all-tree conservative estimate of 0.3 recommended for the root:shoot ratio in *Section A.I.3* above; for shrubs—35% if using other than the generic all-shrub conservative estimate of 0.4 recommended for the root:shoot ratio in *Section A.I.3* above; and for herbaceous vegetation—60%.

A.III. GUIDELINES ON ESTIMATING BIOMASS STOCKS BY FIELD MEASUREMENT

A.III.1. General guidelines on field measurement of biomass

8. For field measurements of biomass in carbon pools, the recommended sample unit is a permanent sample plot[19]. Temporary sample plots may also be used if measurements are only to be carried out at one time. If there are components of the carbon pools that are minor, measurements should be completed at sub-plots within the sample plot. The sub-plots may be of the nested fixed-radius type, or comprise randomly located areas of fixed dimensions.

9. If field measurements are being performed because project participants wish to obtain relatively high-accuracy data, a formal statistical design process will be required to determine the sampling frequency within each stratum, as considered further below. However, if measured data are being obtained only for verification of the applicability of default data, it will usually be sufficient to complete measurements at a minimum of 5 sample plots. Sample plots for verification of default data must be located in a representative manner across the entire project area.

10. The use of mean values of default data (including, as appropriate, data derived from default predictive equations) may be considered valid if the measured data fall within ±10% of the mean default value—and provided that if any bias is evident it results in a conservative estimate of project net anthropogenic removals by sinks.

11. If field-based measurement of biomass is to be used as the primary source of data, the number of sample plots required should be estimated using the latest version of the tool for the "*Calculation of the number of sample plots for measurements within A/R CDM project activities*", approved by the CDM Executive Board[20]. For application to project inventory, the targeted precision level for biomass estimation within each stratum is usually ±10% of the mean at a 95% confidence level. However, when estimating biomass in vegetation existing at the time the project commences, it is expected that biomass levels will be much lower than in the project scenario. As such, estimating existing biomass stocks to a lesser precision is acceptable, as it will have limited influence on the overall accuracy of net anthropogenic removals by sinks: targeting a minimum precision of ±20% of the mean at a 90% confidence level is recommended. To assess whether this precision is reached, an initial set of measurements can be made for 10 sample plots per stratum (which may be the entire project area if

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[19] Whenever dividing the weight of biomass measured in a sample plot to obtain biomass stocks per unit area, it is the area of the sample plot projected into a horizontal plane that must be used in the denominator.

[20] CDM Executive Board Meeting Report EB31, Annex 15: *Calculation of the number of sample plots for measurements within A/R CDM project activities.*

relatively uniform growth conditions exist). More plots can be added if the achieved precision does not approach the targeted precision.

12. There are two circumstances in which a higher precision should be targeted when making measurements of biomass existing in the project area at the time the project commences. The first is when a project is being carried out in a host country that has adopted a high value for the crown cover threshold as part of its forest definition (e.g., 30%). If trees exist in the project area close to that threshold at the time the project commences, and are not protected from felling or burning during site preparation, then emissions resulting from site preparation will be substantial in relation to project removals. In such a case, inventory of existing biomass should attempt to meet the precision normally expected for the project scenario (i.e. an estimate of biomass stocks in each stratum to a targeted precision level of ±10% of the mean at a 95% confidence level). The second situation is when the proposed project plans to implement A/R activities on a fraction of the project area that is not much greater than the host country's forest crown cover threshold. In this case emissions resulting from site preparation could again be substantial in relation to project removals, and so inventory of existing biomass should again attempt to meet a precision of ±10% of the mean at a 95% confidence level.

A.III.2. Estimation of herbaceous biomass

13. The biomass of herbaceous plants can be measured by simple destructive harvesting techniques. Guidance on the procedure can be found in Chapter 4.3.3.5 of the *GPG-LULUCF* (IPCC 2003), which should be consulted as necessary. The key points in the approach to determining above- and below-ground herbaceous biomass can be summarised as:

- Randomly locate at least three[21] small sub-plots (either circular or square) of area about 0.1–0.25 m^2 within each sample plot. All sub-plots should be the same size. A small frame equal in area to a sub-plot is often used to aid this task. Larger sub-plots will be needed if the herbaceous biomass comprises a significant fraction of total biomass, for example when measuring biomass in tall tropical grasses.
- Cut the live vegetation inside each sub-plot to ground level, and pool the cut vegetation by sample plot.
- Weigh the pooled biomass just before taking at least 3 well-mixed sub-samples, record the (wet) weight of each of the sub-samples, and their dry weight following oven-drying at 70ºC. Calculate the average dry-to-wet weight ratio.
- For each sample plot above-ground dry biomass stock per unit area is then calculated as (where references to "existing vegetation" refer to the herbaceous component in this case):

$$B_{AB} = 10\, R_{d/w}\, B_{AB,s\text{-}p} \,/\, \left(A_{s\text{-}p}\, n_{s\text{-}p}\right) \quad \textbf{(A1)}$$

where:

B_{AB}	Above-ground dry biomass stock of existing vegetation; *t d.m.* ha^{-1}
$R_{d/w}$	Average dry-to-wet weight ratio of existing above-ground biomass for the sub-samples; $g\, g^{-1}$
$B_{AB,\, s\text{-}p}$	Above-ground wet biomass of existing vegetation pooled for all sub-plots in a sample plot; *kg*
$A_{s\text{-}p}$	Area of a sub-plot; m^2
$n_{s\text{-}p}$	Number of sub-plots; dimensionless
10	Conversion factor: $kg\, m^{-2}$ to $t\, ha^{-1}$

[21] Use more sub-plots if the cover of herbaceous vegetation is very variable: use of at least 5 sub-plots is suggested in this case.

- Average the above-ground biomass stocks in the sample plots to get the average above-ground biomass stock in $t\ d.m.\ ha^{-1}$ for each stratum (which may be the entire project area).

14. Below-ground herbaceous biomass is determined by:

- Collecting at least two soil cores[22] of known diameter from each sub-plot used to determine above-ground biomass, to the base of the rooting zone—typically cores of at least 100 mm diameter, and 300 mm depth. All cores should have the same dimensions, and must be inserted vertically[23]. Cores should be rejected if inspection of the hole left when the core is removed shows significant lateral intrusion of shrub or tree roots.
- Separating the roots from the soil by washing techniques, and pooling the roots by sample plot. Non-root below-ground biomass (e.g., stolons, rhizomes, and tubers) should be retained during this process, and considered part of the sample.
- Weighing the pooled biomass just before taking at least 3 well-mixed sub-samples, recording the (wet) weight of each of the sub-samples, and the dry weight following oven-drying at 70ºC. Calculate the average dry-to-wet weight ratio.
- For each sample plot below-ground dry biomass stock per unit area is then calculated as (where references to "existing vegetation" refer to the herbaceous component in this case):

$$B_{BB} = 10\, R_{d/w}\, B_{BB,s\text{-}c} \Big/ \left(A_{s\text{-}c}\, n_{s\text{-}c}\right) \qquad \textbf{(A2)}$$

where:

B_{BB}	Below-ground dry biomass stock of existing vegetation; $t\ d.m.\ ha^{-1}$
$R_{d/w}$	Average dry-to-wet weight ratio of existing below-ground biomass for the sub-samples; $g\ g^{-1}$
$B_{BB,\ s\text{-}c}$	Below-ground wet biomass of existing vegetation pooled for all sub-plots in a sample plot; *kg*
$A_{s\text{-}c}$	Cross-sectional area of an individual soil core; m^2
$n_{s\text{-}c}$	Number of soil cores per sample plot; dimensionless
10	Conversion factor: $kg\ m^{-2}$ to $t\ ha^{-1}$

A.III.3. Estimation of existing shrub biomass

15. The biomass of shrubs can be either measured by simple destructive harvesting techniques, or estimated using allometric equations. Guidance on the procedure can be found in Chapter 4.3.3.5 of the *GPG-LULUCF* (IPCC 2003), which should be consulted as necessary. The key points in the approach to determining above- and below-ground shrub biomass can be summarised as:

- Determining shrub biomass exclusively by destructive harvest is likely to be a feasible option if the shrubs are small. Essentially, the procedure for determining above- and below-ground biomass follows that for herbaceous biomass—except that a single sub-plot per sample plot is used. The sub-plot area should be sufficient to include at least 10

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[22] If the soil is too stony to reliably extract soil cores to the base of the rooting zone, excavate all soil to the base of the rooting zone from a known horizontal cross-sectional area. Use the cross-sectional area (in m^2) in place of $A_{s\text{-}c}$ in eqn. (A2). To the extent possible, remove any roots in the excavated soil that are not from herbaceous vegetation.

[23] If the soil surface is not horizontal, measure the slope of the surface so that the equivalent horizontal cross-sectional area of the soil core can be calculated (in m^2) and used as the value of $A_{s\text{-}c}$ in eqn. (A2).

shrubs. At least 10 randomly located[24] soil cores[25] should be taken to estimate below-ground shrub biomass. Sampling to greater depth than for herbaceous vegetation may sometimes be required to include the entire shrub rooting zone. Once harvesting and sub-sampling of biomass is complete, the wet and dry weights determined, and the dry-to-wet biomass weight ratio determined, equations (A1) and (A2) can be used to calculate above- and below-ground biomass stock per unit area—where in this case references to "existing vegetation" refer to the shrub component; and there is only a single sub-plot per sample plot (i.e. $n_{s-p} = 1$).

- If the shrubs are large, then destructive harvest at all sample plots may not be efficient. Instead, it may be advantageous to develop allometric equations for estimation of biomass. Guidance on developing allometric equations can be found in Section 4.3.3.5.1 of the *GPG-LULUCF* (IPCC 2003) and references therein, to which the following points are added:
  - Select individual shrubs to cover as large a range in biomass as possible. At least 20 shrubs will be required, randomly located across the range of growing conditions within the project area (if a single equation is to be developed for the entire project area).
  - The simplest independent variable for shrub biomass estimation will often be the diameter at the base of the plant (usually termed the basal, or collar, diameter), which is measured at ground level on the up-slope side. Crown volume may also be a useful variable (e.g., Coomes *et al.* 2002), as may the number and height of stems per shrub.
  - Harvest the above-ground biomass of each shrub, and weigh it just before taking at least 3 well-mixed sub-samples. Record the wet weight of each of the sub-samples, and the sub-sample dry weights following oven-drying at 70ºC. Calculate the average dry-to-wet weight ratio.
  - Below-ground biomass for each shrub is preferably determined by digging up and washing the entire root mass, and then sub-sampling and oven-drying as for above-ground biomass. Alternatively, if the ground is not stony, it may be determined from a root:shoot ratio established using soil coring techniques, together with sample-plot-based destructive harvest of above-ground biomass as described earlier in this section.

A.III.4. Estimation of existing tree biomass

16. The biomass of trees can be estimated by using either allometric equations or biomass expansion factors (BEFs), in conjunction with plot-based sampling. Any sample plot used for biomass estimation should be large enough to include 10–15 trees. Use of allometric equations is generally considered a more direct approach, and is preferred if suitable equations are available (*GPG-LULUCF*, IPCC 2003). Guidance on estimation of the biomass of trees by using allometric or BEF methods in plot-based sampling schemes is given in Chapter 4.3.3.5 of the *GPG-LULUCF* (IPCC 2003). Key points are summarised below, together with some further guidelines.

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[24] If necessary, segment the sample plot area into zones unlikely to have significant herbaceous or tree roots, and locate soil cores at randomly selected positions inside these zones.

[25] If the soil is too stony to reliably extract soil cores to the base of the rooting zone, excavate all soil to the base of the rooting zone from a known horizontal cross-sectional area equal to at least one quarter of the area of the sub-plot. Use the cross-sectional area (in m^2) in place of A_{s-c} in eqn. (A2). To the extent possible, remove any roots in the excavated soil that are not from shrub vegetation. Alternatively, excavate fully the individual root systems of at least three shrubs selected randomly within the sub-plot, and scale the excavated root biomass to the sub-plot area using measurements of total above-ground biomass in the sub-plot, and the above-ground biomass and root:shoot ratio of the shrubs for which root excavation was performed. In this case, A_{s-c} in eqn. (A2) becomes the sub-plot area.

Allometric method

Step 1. Measure the diameter at breast height (DBH; typically 1.35 m above ground level), and also preferably height, of all trees above some minimum DBH in the sample plots. The minimum DBH may vary depending on tree species and climate. For example, the minimum DBH may be as small as 2.5 cm in arid environments where trees grow slowly, whereas it could be up to 10 cm for warm humid environments where trees grow rapidly (*GPG-LULUCF*, IPCC 2003).

Step 2. Choose an appropriate allometric equation to estimate above-ground biomass[26]:

$$B_{AB,\, per\, tree} = f(DBH, H) \quad \textbf{(A3)}$$

where:

$B_{AB,\, per\, tree}$	Above-ground biomass of individual trees; *t d.m. tree*$^{-1}$
$f(DBH,H)$	An allometric equation linking above-ground biomass per tree (*t d.m. tree*$^{-1}$) to tree diameter at breast height (*DBH*), and possibly also to tree height (*H*).

17. Whenever available, use allometric equations that are species-specific, provided the equations have been derived using a wide range of diameters and heights, based on datasets that comprise at least 20 trees. Otherwise, default equations from IPCC literature, national inventory reports or published peer-reviewed studies may be used—such as those provided in Tables 4.A.1 to 4.A.3 of the *GPG-LULUCF* (IPCC 2003). If default equations are used, it is necessary either to use conservatively predicted values, or to verify the applicability of the equation if mean predicted values are to be used. Allometric equations can be verified by:

- Selecting at least 5 trees covering the range of DBH existing in the project area, and felling and weighing the above-ground biomass to determine the total (wet) weight of the stem, branches and leaf biomass components.
- Extracting and immediately weighing[27] sub-samples from each of the wet stem, branch and leaf biomass components[28], followed by oven drying at 70ºC to determine dry biomass.
- Determining the total dry weight of each tree from the wet weights and the averaged ratios of wet and dry weights of the stem, branch and leaf components.
- If the biomass of the harvested trees is within about ±10% of the mean values predicted by the selected default allometric equation, and is not biased—or if biased is wrong on the conservative side (i.e., use of the equation results in an under- rather than over-estimate of project net anthropogenic removals by sinks)—then mean values from the default equation may be used.

Step 3. Estimate below-ground biomass per tree. This should be done by multiplying above-ground biomass per tree by an appropriate value of the root:shoot ratio selected from existing datasets. *Sections A.I.3 and A.II* contain guidelines on sources of default data for root:shoot ratios and conservative choice of data, respectively. It is recommended that the conservative default value of 0.3 be used for the root:shoot ratio of trees, if no better data are available.

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[26] Allometric equations may also exist for total biomass, but this not usual.

[27] Or, alternatively, seal the sub-samples immediately in plastic bags of known weight, and determine wet weights in the laboratory.

[28] Use at least 3 sub-samples for leaf and branch material, and at least 5 sub-samples for stem wood. If cutting slices of stem or branch wood using a chainsaw, ensure cutting does not cause heating and evaporation of water from the wood before the sub-sample is weighed.

Step 4. Sum the values of above- and below-ground biomass determined for each tree within the sample plot, and divide by the sample plot area to determine biomass stock in units of $t\ d.m.\ ha^{-1}$.

18. As an alternative to *Steps 2 and 3*, project participants may wish to develop a project-specific allometric equations or root:shoot ratios. This is not likely to be a cost-effective option for most projects, but if undertaken it is important to ensure destructive harvest includes as wide a range of tree diameters and heights as possible, and to harvest at least 20 trees. Measurement, sub-sampling and oven-drying procedures for each tree should follow those given in *Step 2*, above.

BEF Method

Step 1. As for Step 1 in the *Allometric Method*, the diameter and preferably height of all trees above some minimum diameter is measured within each sample plot.

Step 2. Estimate the volume of the stem wood of each tree. No IPCC default data are available for this parameter. Neither are default equations available to estimate this parameter, and so equations from national inventory reports or published peer-reviewed studies will be required. It may be possible to combine steps 1 and 2 if field instruments (e.g., a relascope) are available that measure the volume of each tree directly.

19. Note that volumes provided by default equations will usually relate to the merchantable (commercial) portion of the stem wood only. Also, equations may not always be available for tree species that exist within the project area at the time the project commences, as such trees will often have no commercial value. Although equations for alternative species may be used, verification of estimated volume will be required by direct measurement—which is relatively straightforward.

Step 3. Choose a BEF and wood density to convert the biomass in merchantable volume of each tree to total above-ground biomass, given by:

$$B_{AB,\,per\,tree} = V_{M\,,\,per\,tree}\ \ D_V\ \ BEF \qquad \textbf{(A4)}$$

where:

$B_{AB,\,per\,tree}$	Above-ground biomass stock of individual trees; $t\ d.m.\ tree^{-1}$
$V_{M,\,per\,tree}$	Merchantable volume of individual trees; $m^3\ tree^{-1}$
D_V	Wood density appropriate for merchantable stem wood (age dependent, if available); $t\ d.m.\ m^{-3}$
BEF	Biomass expansion factor for conversion of biomass in merchantable volume to total above-ground biomass; $t\ d.m.\ (t\ d.m)^{-1}$

20. Default values for wood density and BEFs can be obtained from national inventory reports or published peer-reviewed studies. Alternatively, data may be obtained from IPCC literature: Tables 3A.1.9 and 3A.1.10[29]of the *GPG-LULUCF* (IPCC 2003), and Tables 4.13 and 4.5[30] of the *AFOLU Guidelines* (IPCC 2006). If default data are used values must be chosen conservatively (see *Section A.II* for guidelines). There are also other considerations to be noted when choosing BEFs conservatively:

- BEFs are age dependent, and use of average data may result in significant errors for both young and old stands—as BEFs are usually large for young stands and quite small for old stands.

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[29] Use the parameter BEF_2 in Table 3A.1.10 in the GPG-LULUCF.
[30] Values of the *BEF* must be derived from the parameter $BCEF_S$ in Table 4.5 according to the equation $BEF = BCEF_S / D_V$, using age-dependent wood density if available.

- The BEFs in IPCC literature and national inventory are usually applicable to closed canopy forest, whereas in most circumstances trees existing with the project boundary at the time the project starts will be growing in open situations—with such trees likely to be carrying more biomass in branches/foliage per unit of stem biomass than trees in closed-canopy situations. For trees existing at the time the project commences it is therefore recommended that the selected BEF be increased by a further 30%.

21. Wood density can also be directly measured, by coring techniques. However, it is not recommended that BEFs be determined by direct measurement. Rather, if destructive harvest to determine BEFs is envisaged, the effort should instead be directed to determining allometric equations for total above-ground biomass (IPCC 2003).

Step 4. Estimate below-ground biomass per tree. This should be done by multiplying above-ground biomass per tree by an appropriate value of the root:shoot ratio selected from existing datasets. *Sections A.I.3 and A.II* contain guidelines on sources of default data for root:shoot ratios and for conservative choice of data, respectively. It is recommended that the conservative default value of 0.3 be used for the root:shoot ratio of trees, if no better data are available.

Step 5. Sum the values of above- and below-ground biomass determined for each tree within the sample plot, and divide by the sample plot area to determine biomass stocks in units of $t\ d.m.\ ha^{-1}$.

References

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IPCC 2003. *Good Practice Guidance for Land Use, Land-use Change and Forestry*. This is available from the IPCC Secretariat (www.ipcc.ch), or may be downloaded from the National Greenhouse Gas Inventory Programme at http://www.ipcc-nggip.iges.or.jp.

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