I. INTRODUCTION

This document outlines the equations used to quantify carbon stocks and GHG emission sources and removals within the project boundary.

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1 Carbon Pools

1.1 Change in Carbon Stock

$$\Delta C = \Delta C_{AGB} + \Delta C_{BGB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO} + \Delta C_{HB} \text{ [1](1.1.1)}$$

Where:

Variable	Description	Unit
ΔC	Change in carbon stock pool	tCO_2e
ΔC_{AGB}	Change in carbon stock of above-ground biomass	tCO_2e
ΔC_{BGB}	Change in carbon stock of below-ground biomass	tCO_2e
ΔC_{DW}	Change in carbon stock of dead wood	tCO_2e
ΔC_{LI}	Change in carbon stock of litter	tCO_2e
ΔC_{SO}	Change in carbon stock of soils	tCO_2e
ΔC_{HB}	Change in carbon stock of herbaceous vegetation biomass	tCO_2e

1.2 Trees & Shrubs Biomass

The carbon stock of above-ground and below-ground biomass includes both trees and shrubs, as such:

$$C_{AGB} = C_{AGB,TREE} + C_{AGB,SHRUB} \quad (1.2.1)$$

$$C_{BGB} = C_{BGB,TREE} + C_{BGB,SHRUB} \quad (1.2.2)$$

Therefore:

$$C_{AGB} + C_{BGB} = C_{TREE} + C_{SHRUB} \quad (1.2.3)$$

Where:

Variable	Description	Unit
$C_{AGB,TREE}$	Carbon stock in above-ground biomass of tree biomass	tCO_2e
$C_{BGB,TREE}$	Carbon stock in below-ground biomass of tree biomass	tCO_2e
$C_{AGB,SHRUB}$	Carbon stock in above-ground biomass of shrub biomass	tCO_2e

[1] Equation 2.3, Volume 4 - 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Variable	Description	Unit
$\boldsymbol{C_{BGB,SHRUB}}$	Carbon stock in below-ground biomass of shrub biomass	tCO_2e
$\boldsymbol{C_{TREE}}$	Carbon stock in tree biomass	tCO_2e
$\boldsymbol{C_{SHRUB}}$	Carbon stock in shrub biomass	tCO_2e

1.2.1 Tree Biomass

Tree biomass refers to the above-ground and below-ground living biomass of trees, such that:

$C_{TREE} = C_{AGB,TREE} + C_{BGB,TREE}$ [2] *(1.2.1.1)*

$\Delta C_{TREE} = C_{TREE,t_2} - C_{TREE,t_1}$ [3] *(1.2.1.2)*

Where:

Variable	Description	Unit
$\boldsymbol{\Delta C_{TREE}}$	Change in carbon stock of tree biomass during the period between the times t_1 and t_2	tCO_2e
$\boldsymbol{C_{TREE,t_2}}$	Carbon stock in tree biomass at time t_2	tCO_2e
$\boldsymbol{C_{TREE,t_1}}$	Carbon stock in tree biomass at time t_1	tCO_2e

At any point in time, the carbon stock in the above-ground living biomass of trees is as such:

$$C_{AGB,TREE,t} = \frac{44}{12} \times f(\rho, DBH, H) \times CF$$

Meanwhile, at any point in time, the carbon stock in the below-ground living biomass of trees is as such:

$$C_{BGB,TREE,t} = \frac{44}{12} \times f(\rho, DBH, H) \times CF \times R$$

Summing the carbon stock of both the AGB and BGB, at any point in time, the carbon stock in the biomass of living trees is as such:

[2] Paragraph 6, Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities, V4.1 (UNFCCC)

[3] Equation 1, Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities, V4.1 (UNFCCC)

$C_{TREE,t} = \frac{44}{12} \times f(\rho, DBH, H) \times CF \times (1 + R)$ [4] *(1.2.1.3)*

Where:

Variable	Description	Unit
$C_{TREE,t}$	Carbon stock in tree biomass at time t	tCO_2e
$f(\rho, DBH, H)$	Allometric function, which is a function of the following variables: ρ = Biomass density DBH = Diameter at breast height H = Tree height	t d.m.
R	Root to shoot ratio	-
CF	Carbon fraction Default factor from IPCC[5] = 0.47	t C (t d.m.)$^{-1}$

The Root to Shoot Ratio, *R*, is dependent on the following factors *[6]*:

If it is a natural forest and the mass of the above-ground biomass is less than 125 tonnes per hectare, *R* = 0.207

If it is a planted forest and the mass of the above-ground biomass is less than 125 tonnes per hectare, *R* = 0.325

If it is a natural forest and the mass of the above-ground biomass is more than 125 tonnes per hectare, *R* = 0.212

1.2.2 Shrub Biomass

Shrub biomass refers to the above-ground and below-ground living biomass of shrubs, such that:

$C_{SHRUB} = C_{AGB,SHRUB} + C_{BGB,SHRUB}$ [2] *(1.2.2.1)*

$\Delta C_{SHRUB} = C_{SHRUB,t_2} - C_{SHRUB,t_1}$ [7] *(1.2.2.2)*

Where:

[4] Equations 7 & 8, Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities, V4.1 (UNFCCC)
[5] Table 4.3, Volume 4 - 2006 IPCC Guidelines for National Greenhouse Gas Inventories
[6] Table 4.4, Volume 4 - 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
[7] Equation 24, Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities, V4.1 (UNFCCC)

Variable	Description	Unit
$\Delta \boldsymbol{C_{SHRUB}}$	Change in carbon stock of shrub biomass during the period between the times t_1 and t_2	tCO_2e
$\boldsymbol{C_{SHRUB,t_2}}$	Carbon stock in shrub biomass at time t_2	tCO_2e
$\boldsymbol{C_{SHRUB,t_1}}$	Carbon stock in shrub biomass at time t_1	tCO_2e

The carbon stock in shrubs at a point in time depends on the shrub crown cover.

For areas with a shrub crown cover of less than 5%, the area will be treated as a single stratum and the shrub biomass in this stratum is estimated as zero. As such, for areas with less than 5% of shrub crown cover:

$C_{SHRUB,t} = 0$ *[8]* *(1.2.2.1)*

Where:

Variable	Description	Unit
$\boldsymbol{C_{SHRUB,t}}$	Carbon stock in shrub biomass at time t	tCO_2e

For the strata with shrub crown cover of greater than 5%, the carbon stock in shrubs at any point in time is estimated as given below. Similar to what was done in Section 1.2.1, the carbon stock in shrubs is multiplied by a factor of $(1 + R_S)$ to account for both the above-ground and below-ground shrub biomass *[9]*:

$$C_{SHRUB,t} = \frac{44}{12} \times CF \times (1 + R_S) \times \sum_i \left(A_{SHRUB,i} \times b_{SHRUB,i}\right) \quad (1.2.2.2)$$

$$b_{SHRUB,i} = BDR_{SF} \times b_{FOREST} \times CC_{SHRUB,i} \quad (1.2.2.2)$$

Where:

Variable	Description	Unit
$\boldsymbol{R_S}$	Root to shoot ratio for shrubs Default factor from UNFCCC[10] = 0.40	-

[8] Paragraph 60, Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities, V4.1 (UNFCCC)

[9] Equation 26 and 27, Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities, V4.1 (UNFCCC)

[10] Derivation of default values for root:shoot ratios is discussed in Annex 1, Section A.I.3, of the approved A/R methodological tool: Estimation of emissions from clearing, burning and decay of existing vegetation due to implementation of an A/R CDM project activity (EB Report 41, Annex 14).

Variable	Description	Unit
$A_{SHRUB,i}$	Area of shrub biomass estimation stratum *i*	ha
$b_{SHRUB,i}$	Shrub biomass per hectare in shrub biomass estimation stratum *i*	t d.m. ha^{-1}
BDR_{SF}	Ratio of shrub biomass per hectare in land having a shrub crown cover of 100% and the default above-ground biomass content in forest in the region/country where the project activity is located Default factor from UNFCCC[11] = 0.10	-
b_{FOREST}	Default above-ground biomass content in forest in Malaysia Default factor from IPCC[12] = 205	t d.m. ha^{-1}
$CC_{SHRUB,i}$	Crown cover of shrubs in shrub biomass estimation stratum *i* at the time of estimation, expressed as a fraction *(e.g. 10% crown cover implies $CC_{SHRUB,i}$ = 0.10)*	-

1.3 Deadwood

$$\Delta C_{DW} = C_{DW,t_2} - C_{DW,t_1} \quad (1.3.1)$$

Where:

Variable	Description	Unit
ΔC_{DW}	Change in carbon stock of dead wood during the period between the times t_1 and t_2	tCO_2e
C_{DW,t_2}	Carbon stock in dead wood at time t_2	tCO_2e
C_{DW,t_1}	Carbon stock in dead wood at time t_1	tCO_2e

The carbon stock in dead wood at any point in time depends on the category of the dead wood. The different categories are as below.

[11] Equation 27, Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities, V4.2 (UNFCCC)
[12] Table 3A.1.4, 2003 Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC)

1.3.1 Standing Biomass – With Branch

Applies to standing dead trees that contain branches and twigs and resembles a live tree (except for leaves) or standing dead trees with only large branches remaining.

The carbon stock of the above-ground and below-ground biomass of the standing dead tree needs to be accounted for. Therefore, similar to what was done in Section 1.2, the formula for the carbon stock is multiplied with a factor of $(1 + R)$.

At any point in time, the carbon stock in dead wood is as such:

$$C_{DW,t} = \frac{44}{12} \times CF \times f(\rho, DBH, H) \times \alpha \times (1 + R) \text{ [13]} \quad (1.3.1.1)$$

Where:

Variable	Description	Unit
$C_{DW,t}$	Carbon stock in dead wood at time *t*	tCO_2e
α	Biomass reduction factor	-

The Biomass Reduction Factor, α, is dependent on the following factors *[14]*:

For standing dead trees which have only lost leaves and twigs, α = 0.975

For standing dead trees with only large branches remaining, α = 0.80

1.3.2 Standing Biomass – No Branch

Applies to standing dead trees that have no branches and is just the bole.

The carbon stock of the above-ground and below-ground biomass of the standing dead tree needs to be accounted for. Therefore, similar to what was done in Section 1.2 and 1.3.1, the formula for the carbon stock is multiplied with a factor of $(1 + R)$.

At any point in time, the carbon stock in dead wood is as such:

$$C_{DW,t} = \frac{44}{12} \times CF \times d \times V_B \times DRF \times (1 + R) \text{ [15]} \quad (1.3.2.1)$$

Where:

Variable	Description	Unit
V_B	Basal tree volume	m^3

[13] Equation 2, Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities, V3.1 (UNFCCC)

[14] Paragraph 14, Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities, V3.1 (UNFCCC)

[15] Equation 5, Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities, V3.1 (UNFCCC)

Variable	Description	Unit
d	Basic wood density	(t d.m.) m^{-3}
DRF	Density reduction factor	-

The Basal Tree Volume, V_B, is given as:

$$V_B = \frac{\pi}{4}(D_{MID})^2 \times H_S \quad (1.3.2.2)$$

Where:

Variable	Description	Unit
D_{MID}	Mid-height diameter	m
H_S	Height of the standing dead tree	m

For standing dead trees with a height less than 4 m, the Mid-height Diameter, D_{MID}, is measured as the diameter at mid-height of the stump *[16]*.

For standing dead trees with a height of more than 4 m, the Mid-height Diameter, D_{MID}, is estimated as:

$$D_{MID} = 0.57 \times DBH \times \left(\frac{H_S}{H_S - H_{DBH}}\right)^{0.80} \text{[17]} \quad (1.3.2.3)$$

Where:

Variable	Description	Unit
H_{DBH}	Height above ground level at which DBH is measured	m

Three density classes define the value of the Density Reduction Factor. To distinguish between these classes, a common practice in the field to determine the is strike the wood with a machete. The results from such a practice and the corresponding Density Reduction Factor[18] are as such:

Sound – The blade bounces off, *DRF* = 1

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16 Paragraph 25, Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities, V3.1 (UNFCCC)
17 Equation 4, Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities, V3.1 (UNFCCC)
18 Paragraph 23 and 24, Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities, V3.1 (UNFCCC)

Intermediate – The blade enters the wood slightly, *DRF* = 0.80

Rotten – The blade causes the wood to fall apart, *DRF* = 0.45

1.3.3 Lying Biomass

Applies to lying dead trees.

The carbon stock of lying dead wood is estimated using the line transect method. Two transect lines, with a combined length of at least 100 meters, are laid out to intersect each other at right angles in the center of the plot. The diameter of each piece of lying dead wood measuring at least 10 cm that crosses these lines is recorded [19].

At any point in time, the carbon stock in dead wood is as such:

$$C_{DW,t} = a_{PLOT} \times \frac{44}{12} \times CF \times d \times V_L \times DRF \ [20] \qquad (1.3.3.1)$$

Where:

Variable	Description	Unit
a_{PLOT}	Area of sample plot	ha
V_L	Volume of lying wood	m^3 ha^{-1}

The volume of lying wood, V_L, is given as:

$$V_L = \frac{\pi^2}{8L} \times \sum_{n=1}^{N} D_n^2 \ [21] \qquad (1.3.3.2)$$

Where:

Variable	Description	Unit
D_n	Diameter of the n^{th} piece of lying dead wood intersecting the transect line	m
L	Sum of the lengths of the transect lines	m

The term $\sum_{n=1}^{N} D_n^2$ is essentially the summation of the square of the diameters of all pieces of lying dead wood that was found to be intersecting the transect line. In this case, it represents the summation

[19] Paragraph 28, Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities, V3.1 (UNFCCC)
[20] Equation 6, Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities, V3.1 (UNFCCC)
[21] Equation 4.3.2 (Dead Wood - Volume of Lying Dead Wood) and Section 4.3.3.5.3 (Density measurements and Standing dead wood), 2003 Good Practice Guidance for Land Use, Land-Use Change and Forestry

up to the N[th] wood that was found to be intersecting the transect line. As such, this term can also be represented as $(D_1^2 + D_2^2 + \cdots + D_N^2)$.

The value of the *DRF* for Lying Biomass is the same as Standing Biomass, as such, the values of the *DRF* follow those that were provided in Section 1.3.2 above.

1.4 Litter

$$\Delta C_{LI} = C_{LI,t_2} - C_{LI,t_1} \quad (1.4.1)$$

Where:

Variable	Description	Unit
ΔC_{LI}	Change in carbon stock of litter during the period between the times t_1 and t_2	tCO_2e
C_{LI,t_2}	Carbon stock in litter at time t_2	tCO_2e
C_{LI,t_1}	Carbon stock in litter at time t_1	tCO_2e

To estimate the carbon stock in litter, four litter samples are collected from each sample plot, using a sampling frame that is place in four randomly selected positions within the plot.

At any point in time, the carbon stock in litter for the sampling frames are as such:

$$C_{LI,FRAME,t} = \frac{44}{12} \times 10 \times \frac{1}{4 \times a_{FRAME}} \times B_{LI} \times DWR_{LI} \times CF_{LI} \quad (1.4.2)$$
[22]

Where:

Variable	Description	Unit
$C_{LI,FRAME,t}$	Carbon stock in litter at time t for the sampling frames	tCO_2e
a_{FRAME}	Area of sampling frame	m^2
B_{LI}	Weight of composite litter	Kg
DWR_{LI}	Dry-to-wet ratio	-
CF_{LI}	Carbon fraction of dry biomass in litter Default factor from UNFCC[23] = 0.3722	-

[22] Equation 12, Estimation of carbon stocks and change in carbon stocks in dead wood and litter in A/R CDM project activities, V3.1 (UNFCCC)
[23] Ibid

To obtain the carbon stock in litter for the entire sample plot:

$$C_{LI,t} = \frac{44}{12} \times 10 \times \frac{a_{PLOT}}{4 \times a_{FRAME}} \times B_{LI} \times DWR_{LI} \times CF_{LI} \quad (1.4.3)$$

Where:

Variable	Description	Unit
$C_{LI,t}$	Carbon stock in litter at time *t* for the sample plot	tCO_2e
a_{PLOT}	Area of sample plot	ha

1.5 Soils

$$\Delta C_{SO} = C_{SO,t_2} - C_{SO,t_1} \quad (1.5.1)$$

Where:

Variable	Description	Unit
ΔC_{SO}	Change in carbon stock of soil during the period between the times t_1 and t_2	tCO_2e
C_{SO,t_2}	Carbon stock in soil at time t_2	tCO_2e
C_{SO,t_1}	Carbon stock in soil at time t_1	tCO_2e

At any point in time, the carbon stock in soil is as such:

$$C_{SO,t} = \frac{44}{12} \times A \times SOC_{REF} \times f_{LU} \times f_{MG} \times f_{IN} \text{ [24]} \quad (1.5.2)$$

Where:

Variable	Description	Unit
$C_{SO,t}$	Carbon stock in soil at time *t*	tCO_2e
A	Area of land	ha
SOC_{REF}	Reference soil organic carbon stock	$t\ C\ ha^{-1}$

[24] Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities, V1.1 (UNFCCC) *(Note: CDM has adopted IPCC Guidelines and summarized from Cropland and Grassland)*

Variable	Description	Unit
f_{LU}	Relative stock change factor for land-use	-
f_{MG}	Relative stock change factor for management regime	-
f_{IN}	Relative stock change factor for input of organic matter	-

The values of SOC_{REF}, f_{LU}, f_{MG} and f_{IN} are obtained from Tables 3 to 6 in the Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities, V1.1 (UNFCCC).

1.6 Herbaceous Vegetation Biomass

The carbon stock of herbaceous vegetation biomass is calculated, as such:

$$\Delta C_{HB} = A_{i,t} \times \frac{C_{HB,i,t_2} - C_{HB,i,t_1}}{t_2 - t_1} \times \frac{44}{12} \quad (1.6.1[25])$$

Where:

Variable	Description	Unit
ΔC_{HB}	Change in carbon stock of herbaceous vegetation biomass	$tCO_2e\ yr^{-1}$
$A_{i,t}$	Size of area of stratum i in year t	ha
C_{HB,i,t_2}	Carbon stock in herbaceous vegetation biomass at time t_2	tC
C_{HB,i,t_1}	Carbon stock in herbaceous vegetation biomass at time t_1	tC
i	1, 2, 3 … M_{FCO} strata in project scenario 1, 2, 3 …. M_{BSL} strata in baseline scenario	-
t	1, 2, 3 … year since the project	yr
$\frac{44}{12}$	Conversion factor from C to CO_2 (i.e., ratio of the molecular weight of carbon dioxide to carbon[26])	-

[25] IPCC Chapter 2 Equation 2.8
[26] Greenhouse Gas Equivalencies Calculator - Calculations and References, US EPA, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator-calculations-and-references

For coastal wetlands with herbaceous vegetation (e.g., seagrass meadows, salt marshes), the annual increase in biomass stock is assumed to be offset by losses due to natural mortality within the same year[27]. As such, carbon stock increases from (re)vegetation in these systems may only be credited in the first year of the project crediting period.

2 GHG Emission Sources

2.1 Soil

Net GHG emissions from soil determined for each stratum, is estimated by:

$$GHG_{SOC,i,t} = GHG_{SOC-CO2,i,t} + GHG_{SOC-CH4,i,t} + GHG_{SOC-N2O,i,t} \quad (2.1.1)$$

Where:

Variable	Description	Unit
$\boldsymbol{GHG_{SOC,i,t}}$	Net GHG emissions from soil per stratum i in year t	$tCO_2e\ yr^{-1}$
$\boldsymbol{GHG_{SOC-CO2,i,t}}$	CO_2 emissions from the SOC pool per stratum i in year t	$tCO_2e\ yr^{-1}$
$\boldsymbol{GHG_{SOC-CH4,i,t}}$	CH_4 emissions from the SOC pool per stratum i in year t	$tCO_2e\ yr^{-1}$
$\boldsymbol{GHG_{SOC-N2O,i,t}}$	N_2O emissions from the SOC pool per stratum i in year t	$tCO_2e\ yr^{-1}$

Where the estimated GHG emissions for soil are assumed to be zero for each stratum if the project year exceeds the PDT or SDT, calculated based on Section 3.2 of the Coastal Wetland Restoration methodology, as follows:

For organic soils, where $t > t_{PDT-BSL,i}$: $GHG_{SOC,i} = 0$

For mineral soils, where $t > t_{SDT-BSL,i}$: $GHG_{SOC,i} = 0$

2.1.1 CO_2 Emissions

CO_2 emissions is quantified by the emissions of in-situ/drained, excavated and eroded soil, as follows:

$$GHG_{SOC-CO2,i,t} = GHG_{SOC-drain-CO2,i,t} + GHG_{SOC-excav-CO2,i,t} + GHG_{SOC-eroded-CO2,i,t} \quad (2.1.1.1)$$

Where:

Variable	Description	Unit
$\boldsymbol{GHG_{SOC-CO2,i,t}}$	CO_2 emissions from the SOC pool per stratum i in year t	$tCO_2e\ yr^{-1}$
$\boldsymbol{GHG_{SOC-drain-CO2,i,t}}$	CO_2 emissions from the SOC pool of in-situ or drained soil per stratum i in year t	$tCO_2e\ yr^{-1}$

[27] IPCC

Variable	Description	Unit
$GHG_{SOC-excav-CO2,i,t}$	CO_2 emissions from the SOC pool of excavated soil per stratum i in year t	$tCO_2e\ yr^{-1}$
$GHG_{SOC-eroded-CO2,i,t}$	CO_2 emissions from the SOC pool of eroded soil per stratum i in year t	$tCO_2e\ yr^{-1}$

2.1.1.1 In-situ or Drained Soil

CO_2 emissions from drained soil is calculated as follows:

$$GHG_{SOC-drain-CO2,i,t} = A_{drain,i,t} \times EF_{drain} \times \frac{44}{12} \qquad (2.1.1.2)$$

Where:

Variable	Description	Unit
$GHG_{SOC-drain-CO2,i,t}$	CO_2 emissions from the SOC pool of in-situ or drained soil per stratum i in year t	$tCO_2e\ yr^{-1}$
$A_{drain,i,t}$	Size of area of drained soil in stratum i in year t	$ha\ yr^{-1}$
EF_{drain}	Emission factor of drained soil Default factor from IPCC[28] for mangroves and tidal marshes = 7.9	$tC\ ha^{-1}$
i	1, 2, 3 … M_{FCO} strata in project scenario 1, 2, 3 …. M_{BSL} strata in baseline scenario	-
$\frac{44}{12}$	Conversion factor from C to CO_2 (i.e., ratio of the molecular weight of carbon dioxide to carbon[29])	

In the case of seagrass meadows areas where soil remains saturated, even when vegetation is absent (i.e., unvegetated seabed)[30] shall not be eligible for the application of any default factor.

Conversely, in areas that have been restored, in particular, those that are both saturated and revegetated, a default emission factor may be applied to account for carbon sequestration, provided that a deduction is made for allochthonous soil organic carbon, as below:

[28] Table 4.13, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC)
[29] Greenhouse Gas Equivalencies Calculator - Calculations and References, US EPA, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator-calculations-and-references
[30] IPCC

$$GHG_{SOC-drain-CO2,i,t} = A_{i,t} \times \left(EF_{in-situ} \times \frac{44}{12}\right)\left(1 - C_{alloch,i,t}\right) \quad (2.1.1.3)$$

Where:

Variable	Description	Unit
$GHG_{SOC-drain-CO2,i,t}$	CO_2 emissions from the SOC pool of in-situ or drained soil per stratum i in year t	$tCO_2e\ yr^{-1}$
A_i	Size of area of drained soil in stratum i in year t	$ha\ yr^{-1}$
$EF_{in-situ}$	SOC accumulation factor of in-situ soil Default factors[31] for each ecosystem as per Table 1. This must be adjusted according to the vegetative cover, as per Table 2	$tC\ ha^{-1}$
$\frac{44}{12}$	Conversion factor from C to CO_2 (i.e., ratio of the molecular weight of carbon dioxide to carbon[32])	-
$1 - C_{alloch,i,t}$	Deduction for Deduction from CO_2 sequestration in the SOC pool to account for the percentage of the carbon stock that is derived from allochthonous soil organic carbon;	-

For $EF_{in-situ}$, the following default factors may be used:

Table 1: Emission Factors at Initiation of Vegetation Reestablishment

Project Area	$EF_{in-situ}$ ($t\ C\ ha^{-1}$)[33]
Mangrove	-1.62
Marsh	-0.91
Seagrass	-0.43

To reflect the progressive nature of vegetation reestablishment, this factor is only applied to strata where vegetative cover exceeds defined thresholds. The IPCC Wetlands Supplement recommends applying default removal factors only where canopy cover exceeds 10%; in this methodology, a more conservative threshold of 15% is used. Areas below 15% are excluded, with the factor scaled

[31] Global carbon sequestration in tidal, saline wetland soils, Chmura et al., 2003
[32] Greenhouse Gas Equivalencies Calculator - Calculations and References, US EPA, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator-calculations-and-references
[33] Table 4.12, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC)

proportionally between 15–50%, and fully applied above 50% cover, consistent with the initiation phase of restoration:

Table 2: Emission Factors for In-Situ Soil Based on Vegetative Cover

Vegetation Cover (%)	$EF_{in-situ}$
≥ 50%	Full default applied
15% – <50%	Linearly reduced
< 15%	Zero, where SOC accumulation and hence sequestration is assumed to be insignificant

The value of $C_{alloch,i,t}$ must be determined by the project proponent based on site-specific evidence or conservative values.

2.1.1.2 Excavated Soil

CO_2 emissions from excavated soil is calculated as follows:

$$GHG_{SOC-excav-CO2,i,t} = A_{excav,i,t} \times C_{soc-prev} \times \frac{44}{12} \quad (2.1.1.4)$$

Where:

Variable	Description	Unit
$GHG_{SOC-excav-CO2,i,t}$	CO_2 emissions from the SOC pool of excavated soil per stratum i in year t	$tCO_2e\ yr^{-1}$
$A_{excav,i,t}$	Size of area of excavated soil in stratum i in year t	$ha\ yr^{-1}$
$C_{soc-prev}$	Carbon stock of soil before soil disturbance Default factor from IPCC, as per Table 3	$t\ C\ ha^{-1}$
i	1, 2, 3 … M_{FCO} strata in project scenario 1, 2, 3 …. M_{BSL} strata in baseline scenario	-
$\frac{44}{12}$	Conversion factor from C to CO_2 (i.e., ratio of the molecular weight of carbon dioxide to carbon[34])	

[34] Greenhouse Gas Equivalencies Calculator - Calculations and References, US EPA, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator-calculations-and-references

For the $C_{soc-prev}$ the following Default Factors may be used:

Table 3: Default Factors for Carbon Stock of Soil Before Disturbance

Project Area	Soil Type	$C_{soc-prev}$ (t C ha^{-1})[35]
Mangrove	Organic	471
	Mineral	286
	Combination	386
Marsh	Organic	340
	Mineral	226
	Combination	255
Seagrass	Mineral – seagrass is assumed to be on mineral soils	108

2.1.1.3 Eroded Soil

CO_2 emissions from eroded soil is calculated as follows:

$$GHG_{SOC-eroded-CO2,i,t} = A_{eroded,i,t} \times C_{soc-prev} \times C_{\%loss-eroded} \times \frac{44}{12} \quad (2.1.1.5)$$

Where:

Variable	Description	Unit
$\boldsymbol{GHG_{SOC-eroded-CO2,i,t}}$	CO_2 emissions from the SOC pool of eroded soil per stratum i in year t	$tCO_2e\ yr^{-1}$
$\boldsymbol{A_{eroded,i,t}}$	Size of area of eroded soil in stratum i in year t	ha yr^{-1}
$\boldsymbol{C_{soc-prev}}$	Carbon stock of soil before soil disturbance Default factor from IPCC, as per Table 3	t C ha^{-1}
$\boldsymbol{C_{\%loss-eroded}}$	Percentage loss of soil organic carbon in stratum i in year t Default factor as per Table 4	%

[35] Table 4.11, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC)

Variable	Description	Unit
i	1, 2, 3 … M_{FCO} strata in project scenario 1, 2, 3 …. M_{BSL} strata in baseline scenario	-
$\frac{44}{12}$	Conversion factor from C to CO_2 (i.e., ratio of the molecular weight of carbon dioxide to carbon[36])	

For the $C_{\%loss-eroded}$ the following Default Factors may be used:

Table 4: Default Factors for Carbon Stock of Soil in Specified CPDE

Project Area	Carbon Preservation Depositional Environment	$C_{\%loss-eroded}$[37]
Land eroded and connected to the estuary	• Normal Marine; or • Deltaic fluidized muds	80
	Normal Marine and sediment deposition rate (sediment accumulation rate) less than 0.002 grams per square centimeter per year	98.5
	O_2 depletion	53
	Small Mountainous Rivers	39
	Extreme accumulation rates	49
Land eroded, but is not connected to the estuary or the open sea	The baseline is more eroded than the project	0
	The baseline is less eroded than the project	100

[36] Greenhouse Gas Equivalencies Calculator - Calculations and References, US EPA, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator-calculations-and-references
[37] The Fate of Terrestrial Organic Carbon in the Marine Environment, Neal E. Blair and Robert C. Aller, 21 September 2011

2.1.2 CH_4 Emissions

Activities that rewet drained soils can shift microbial decomposition from aerobic to anaerobic conditions, potentially increasing CH_4 emissions[38]. The estimation of emissions is proxied using soil salinity, given the relationship between salinity levels and CH_4 emissions in coastal wetlands[39].

CH_4 emissions from soil are calculated as follows:

$$GHG_{SOC-CH4,i,t} = A_{i,t} \times EF_{CH4} \times GWP_{CH4} \quad (2.1.2.1)$$

Where:

Variable	Description	Unit
$GHG_{SOC-CH4,i,t}$	CH_4 emissions from the SOC pool per stratum i in year t	$tCO_2e\ yr^{-1}$
$A_{i,t}$	Size of area in stratum i in year t	$ha\ yr^{-1}$
EF_{CH4}	Emission factor of CH_4 emissions based on soil salinity Default factor from IPCC, as per Table 5	$t\ C\ ha^{-1}$
GWP_{CH4}	Global warming potential of methane	-
i	1, 2, 3 … M_{FCO} strata in project scenario 1, 2, 3 …. M_{BSL} strata in baseline scenario	-

For the EF_{CH4} the following Default Factors may be used:

Table 5: Emission Factor of Methane Emissions Based on Salinity Values

Salinity (ppt)	EF_{CH4} [40]
>18	0
<18	193.7

2.1.3 N_2O Emissions

N_2O emissions from soil are calculated as follows:

[38] 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC)
[39] Ibid
[40] Table 4.14, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (IPCC)

$$GHG_{SOC-N2O,i,t} = A_{i,t} \times EF_{N2O} \times GWP_{N2O} \quad (2.1.3.1)$$

Where:

Variable	Description	Unit
$GHG_{SOC-N2O,i,t}$	N_2O emissions from the SOC pool per stratum i in year t	$tCO_2e\ yr^{-1}$
$A_{i,t}$	Size of area in stratum i in year t	$ha\ yr^{-1}$
EF_{N2O}	Emission factor of N_2O emissions based on soil salinity Default factor as per Table 6	$t\ C\ ha^{-1}$
GWP_{N2O}	Global warming potential of nitrous oxide	-
i	1, 2, 3 … M_{FCO} strata in project scenario 1, 2, 3 …. M_{BSL} strata in baseline scenario	-

For the EF_{N2O} the following Default Factors may be used:

Table 6: Emission Factor of Nitrous Oxide Emissions Based on Salinity Values

Project Area	Salinity (ppt)	EF_{N2O} (%)[41]
Open Water Systems (Seagrass and Salt Marshes)	>18	0.000157
	>5 to ≤18	0.000033
	≤5	0.000053
Mangrove and Nipa	>18	0.000487
	>5 to ≤18	0.000754
	≤5	0.000864

2.2 Fossil Fuel

The net GHG emissions from fossil fuel combustion in project activities is given by:

[41] Nitrous oxide emission from Gulf Coast wetlands , Smith, CJ, RD DeLaune, and WH Patrick Jr, October 1983

$GHG_{FC,t} = \sum_{j=1}^{J} GHG_{FC,j,t}$ [42] (2.2.1)

Where:

Variable	Description	Unit
$GHG_{FC,t}$	CO_2 emissions from fossil fuel combustion during the year *t*	tCO_2
$GHG_{FC,j,t}$	CO_2 emissions from fossil fuel combustion in vehicle/equipment type *j* during the year *t*	tCO_2/yr
j	Type of vehicle/equipment	-
J	Total number of types of vehicles and equipment used in the project activity	-

Note that for fossil fuel combustion in project activities only CO_2 emissions should be considered.

The following two methods can be used to estimate the emissions from fossil fuel combustion.

2.2.1 Direct Method

The direct method assumes that the data on the amount of fuel combusted is available. As such, it can be used when the vehicle or equipment is captive, and the entire fuel consumption can be monitored. The equation used in this method is as such:

$GHG_{FC,j,t} = \sum_{i=1}^{I} \left(FC_{i,j,t} \times EF_{CO_2 i} \times NCV_i \right)$ [43] (2.2.1.1)

Where:

Variable	Description	Unit
$FC_{i,j,t}$	Quantity of fuel type *i* consumed in vehicle/equipment type *j* during the year *t*	Mass or volume unit/yr
$EF_{CO_2 i}$	CO_2 emission factor of the fuel type *i* combusted	tCO_2/GJ
NCV_i	Net calorific value of fuel *i*	GJ/mass or volume unit
i	Fuel type combusted	-

[42] Equation 1, Estimation of GHG emissions related to fossil fuel combustion in A/R CDM project activities, V01 (UNFCCC)
[43] Equation 2, Estimation of GHG emissions related to fossil fuel combustion in A/R CDM project activities, V01 (UNFCCC)

Variable	Description	Unit
I	Total number of fuel types	-

2.2.2 Indirect Method

If the data on the amount of fuel combusted is not available, the indirect method can be used. The equations used in this method are as below [44].

2.2.2.1 Vehicles

$$GHG_{FC,j,t} = \sum_{i=1}^{I}\left(n \times \frac{MT_{j,t}}{TL_{j,t}} \times AD_{j,t} \times SECk_{j,i,t} \times EF_{CO_2 i} \times NCV_i\right) \quad (2.2.2.1.1)$$

$$GHG_{FC,j,t} = \sum_{i=1}^{I}\left(NV_{j,t} \times TD_{j,t} \times SECk_{j,i,t} \times EF_{CO_2 i} \times NCV_i\right) \quad (2.2.2.1.2)$$

$$GHG_{FC,j,t} = \sum_{i=1}^{I}\left(MT_{j,t} \times TD_{j,t} \times SECkt_{j,i,t} \times EF_{CO_2 i} \times NCV_i\right) \quad (2.2.2.1.3)$$

Where:

Variable	Description	Unit
n	Indicator of return load	-
$MT_{j,t}$	Total mass transported by vehicle type *j* during year *t*	tonne
$TL_{j,t}$	Load capacity of vehicle type *j* during year *t*	tonne
$AD_{j,t}$	Average single-trip distance for vehicle type *j* during year *t*	km
$SECk_{j,i,t}$	Specific energy consumption of vehicle type *j* for fuel *I* during year *t*	Quantity of fuel/km
NCV_i	Net calorific value of fuel *i*	GJ/mass or volume unit
$NV_{j,t}$	Number of vehicle type *j* during year *t*	-
$TD_{j,t}$	Total travel distance (including the return trip) for vehicle type *j* during year *t*	km

[44] Equations 3a, 3b, 3c & 4, Estimation of GHG emissions related to fossil fuel combustion in A/R CDM project activities, V01 (UNFCCC)

Variable	Description	Unit
$SECkt_{j,i,t}$	Specific energy consumption of vehicle type *j* for fuel *I* during year *t*	Quantity of fuel/tonne-km

Approach 2.2.2.1.1 is preferred to 2.2.2.1.2, and 2.2.2.1.2 to 2.2.2.1.3.

Where the total mass transported, $\mathrm{MT_{j,t}}$, cannot be obtained according to vehicle types, then $(\mathrm{MT_{j,t}/TL_{j,t}})$ can be substituted by $(\mathrm{MT_t/TL_{av,t}})$ where $\mathrm{MT_t}$ is the total mass transported, and $\mathrm{TL_{av,t}}$ is the indicative load capacity of the fleet (i.e. the type of vehicle which has carried the most load).

For parameters in $\mathrm{SECk_{j,i,t}}$ equation 2.2.2.1.2 and $\mathrm{SECkt_{j,i,t}}$ in equation 2.2.2.1.3, a reference figure can be used. These parameters will be verified to ensure that the conditions which the parameters apply correspond to the situation of the project activity, or that a more conservative assumption is used.

2.2.2.2 Equipment

$$GHG_{FC,j,t} = \sum_{i=1}^{I}\left(NE_{j,t} \times TU_{j,t} \times SECu_{j,i,t} \times EF_{CO_2 i} \times NCV_i\right) \quad (2.2.2.2.1)$$

Where:

Variable	Description	Unit
$NE_{j,t}$	Number of equipment type *j* during year *t*	-
$TU_{j,t}$	Total use for equipment type *j* during year *t*	hours
$SECu_{j,i,t}$	Specific energy consumption of equipment type *j* for fuel *i* during year *t*	Quantity of fuel/hour

2.3 Burning of Biomass

The emission of non-CO_2 GHG resulting from the burning of biomass in project activities is estimated as follows:

$$GHG_{BURN,t} = GHG_{SPF,t} + GHG_{FMF,t} + GHG_{FF,t} \text{ [45]} \quad (2.3.1)$$

Where:

Variable	Description	Unit
$GHG_{BURN,t}$	Emission of non-CO_2 GHGs resulting from burning of biomass and forest fires within the project boundary in year *t*	tCO_2e

[45] Equation 1, Estimation of non-CO2 GHG emissions resulting from burning of biomass attributable to an A/R CDM project activity, V04 (UNFCCC)

Variable	Description	Unit
$\boldsymbol{GHG_{SPF,t}}$	Emission of non-CO_2 GHG s resulting from use of fire in site preparation in year *t*	tCO_2e
$\boldsymbol{GHG_{FMF,t}}$	Emission of non-CO_2 GHGs resulting from use of fire to clear the land of harvest residue prior to replanting of the land or other forest management, in year *t*	tCO_2e
$\boldsymbol{GHG_{FF,t}}$	Emission of non-CO_2 GHGs resulting from fire in year *t*	tCO_2e

2.3.1 Use of Fire in Site Preparation

The approach to estimate the emission of non-CO_2 GHGs from the use of fire in site preparation depends on a few conditions [46].

For all areas of land where:

i. Slash-and-burn is a common practice in the baseline, and
ii. Fire has been used in the area at least once during the period of ten years preceding the start of the project activity:

$$GHG_{SPF,t} = 0 \quad (2.3.1.1)$$

For all other areas of land where the two conditions above are not satisfied:

$$GHG_{SPF,t} = 0.07 \times \sum_{i=1}^{I} \left(A_{SPF,i,t} \times \frac{44}{12} \times \left(CF_{TREE} \times b_{TREE,i,t} + CF_{SHRUB} \times BDR_{SF} \times B_{FOREST} \times CC_{SHRUB,i,t} \right) \right) \quad (2.3.1.2)$$

Where:

Variable	Description	Unit
$\mathbf{0.07}$	Ratio of non-CO_2 GHG emissions to CO_2 emission resulting from burning of biomass *Note: The value of this ratio has been adapted from Table 2.5 of the 2006 IPCC Guidelines for National GHG Inventories, taking into account CH_4 and N_2O emissions only.*	-
$\boldsymbol{b_{TREE,i,t}}$	Mean tree biomass per hectare within stratum *i* in the project boundary at the start of the project	t d.m. ha^{-1}

[46] Paragraph 7, Estimation of non-CO2 GHG emissions resulting from burning of biomass attributable to an A/R CDM project activity, V04 (UNFCCC)

Variable	Description	Unit
	Estimated using the equations in Section 1.2.1. Where pre-project living trees are not burned during site preparation, this shall be set equal to zero	
CF_{TREE}	Carbon fraction of biomass Default factor from IPCC[47] = 0.50	t C (t d.m.)$^{-1}$
CF_{SHRUB}	Carbon fraction of shrub biomass Default factor from IPCC[48] = 0.50	t C (t d.m.)$^{-1}$
$A_{SPF,t}$	Area of land in which fire is used in site preparation in stratum *i* in year *t*	ha
BDR_{SF}	Ratio of shrub biomass per unit area in land having a shrub crown cover of 1.0 and the default above-ground biomass content in forest in the region/country where the project is located Default factor = 0.10 (used unless transparent and verifiable information can be provided to justify a different value)	-
B_{FOREST}	Default above-ground biomass content in forest in the region/country where the project is located Default factor from IPCC[49] = 205	t d.m. ha^{-1}
$CC_{SHRUB,i,t}$	Crown cover of shrubs in area of land within the project boundary at the start of the project in which fire is used for site preparation in stratum *i* in year *t*	-
i	Stratum within the baseline	-

2.3.2 Use of Fire to Clear Land of Harvest Residue

The emission of non-CO_2 GHG resulting from the use of fire to clear the land of harvest residue prior to replanting of the land is estimated as follows:

$$GHG_{FMF,t} = 0.07 \times \frac{44}{12} \times B_{HARVEST,t} \times f_{BL} \times CF_{TREE} \quad [50] \qquad (2.3.2.1)$$

Where:

[47] Section 3.2, 2003 Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC)
[48] Ibid
[49] Table 3A.1.4, 2003 Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC)
[50] Equation 4, Estimation of non-CO2 GHG emissions resulting from burning of biomass attributable to an A/R CDM project activity, V04 (UNFCCC)

Variable	Description	Unit
$B_{HARVEST,t}$	Biomass harvested from area subjected to use of fire to clear the land of harvest residue prior to replanting of the land in year *t*	t d.m.
f_{BL}	The fraction of above-ground tree biomass out of total harvest left on-site For tropical forest, default factor from IPCC = 0.25	-

If the data on the biomass of the harvest removed is not available, the biomass of harvest removed can be estimated by:

$$B_{HARVEST,t} = \frac{B_{FOREST}}{BEF_2} \times A_{FMF,t} \text{ [51]} \quad (2.3.2.2)$$

Where:

Variable	Description	Unit
BEF_2	Biomass expansion factor for trees harvested Default factor from UNFCCC[52] = 1.25	-
$A_{FMF,T}$	Area of land subjected to use of fire to clear the land of harvest residue prior to replanting of the land in year *t*	ha

2.3.3 Forest Fire

Forest fire is defined as the burning of above-ground biomass in fire that is not site preparation or burning of harvest residue. The emission of GHGs resulting from forest fires is calculated as such:

$$GHG_{FF,t} = GHG_{FF\_TREE,t} + GHG_{FF\_DOM,t} \text{ [53]} \quad (2.3.3.1)$$

Where:

Variable	Description	Unit
$GHG_{FF\_TREE,t}$	Emission of non-CO_2 GHGs resulting from the loss of above-ground biomass of trees due to forest fire	tCO_2e
$GHG_{FF\_DOM,t}$	Emission of non-CO_2 GHGs resulting from the loss of dead organic matter due to forest fire	tCO_2e

[51] Equation 5, Estimation of non-CO2 GHG emissions resulting from burning of biomass attributable to an A/R CDM project activity, V04 (UNFCCC)
[52] IPCC 2006 Guidelines for National Greenhouse Gas Inventories. Chapter 4: Forestry: Volume 4: Agriculture, Forestry and Other Land Use
[53] Equation 6, Estimation of non-CO2 GHG emissions resulting from burning of biomass attributable to an A/R CDM project activity, V04 (UNFCCC)

2.3.3.1 Loss of Above-ground Biomass of Trees

$$GHG_{FF\_TREE,t} = 0.001 \times \sum_{i=1}^{I} \left(A_{BURN,i,t} \times b_{TREE,i,t_L} \times COMF_i \times \left(EF_{CH4,i} \times GWP_{CH4} + EF_{N2O,i} \times GWP_{N2O} \right) \right) [54] \quad (2.3.3.1.1)$$

Where:

Variable	Description	Unit
$A_{BURN,i,t}$	Area burnt in stratum *i* in year *t*	ha
$b_{TREE,t}$	Mean above-ground tree biomass per hectare in stratum *i* in year t_L t_L is the year in which the last verification was carried out before occurrence of the fire Where above-ground biomass of living trees was not burnt by fire, this may be set equal to zero	t d.m. ha^{-1}
$COMF_i$	Combustion factor for stratum *i*	-
$EF_{CH4,i}$	Emission factor for CH_4 in stratum *i*	g CH_4 (kg dry matter $burnt)^{-1}$
GWP_{CH4}	Global warming potential for CH_4 Default factor from UNFCCC[55] = 21	-
$EF_{N2O,i}$	Emission factor for N_2O in stratum *i*	g N_2O (kg dry matter $burnt)^{-1}$
GWP_{N2O}	Global warming potential for N_2O Default factor from UNFCCC[56] = 310	-

2.3.3.2 Loss of Dead Organic Matter

$$GHG_{FF\_DOM,t} = 0.07 \times \sum_{i=1}^{I} \left(A_{BURN,i,t} \times \left(C_{DW,i,t_L} + C_{LI,i,t_L} \right) \right) [57] \quad (2.3.3.2.1)$$

[54] Equation 7, Estimation of non-CO2 GHG emissions resulting from burning of biomass attributable to an A/R CDM project activity, V04 (UNFCCC)
[55] Global Warming Potentials (IPCC Second Assessment Report), UNFCCC
[56] Ibid
[57] Equation 8, Estimation of non-CO2 GHG emissions resulting from burning of biomass attributable to an A/R CDM project activity, V04 (UNFCCC)

Where:

Variable	Description	Unit
C_{DW,i,t_L}	Carbon stock in dead wood in stratum *i* in year t_L t_L is the year in which the last verification was carried out before occurrence of the fire Estimated using the approach described in Section 1.3	tCO_2e
C_{LI,i,t_L}	Carbon stock in litter in stratum *i* in year t_L t_L is the year in which the last verification was carried out before occurrence of the fire Estimated using the approach described in Section 1.4	tCO_2e

3 Uncertainty Analysis

The procedure below is to estimate the uncertainty in the estimation of GHG emissions and carbon stock changes for both the baseline and project estimations *[58]*.

Step 1: Calculate percentage uncertainty in the combined carbon stocks and GHG sources in stratum for the baseline estimates and ex-post project

For the baseline scenario:

$$Uncertain_{BSL,i} = \frac{\sqrt{(U_{BSL,SS1,i} \times E_{BSL,SS1,i})^2 + (U_{BSL,SS1,i} \times E_{BSL,SS1,i})^2 \ldots + \cdots (U_{BSL,SSn,i} \times E_{BSL,SSn,i})^2}}{|E_{BSL,SS1,i} + E_{BSL,SS2,i} \ldots + \cdots E_{BSL,SSn,i}|} \qquad (3.1)$$

For the project scenario:

$$Uncertain_{FCO,i} = \frac{\sqrt{(U_{FCO,SS1,i} \times E_{FCO,SS1,i})^2 + (U_{FCO,SS2,i} \times E_{FCO,SS2,i})^2 \ldots + \cdots (U_{FCO,SSn,i} \times E_{FCO,SSn,i})^2}}{|E_{FCO,SS1,i} + E_{FCO,SS2,i} \ldots + \cdots E_{FCO,SSn,i}|} \qquad (3.2)$$

Where:

Variable	Description	Unit
$Uncertain_{BSL,i}$	Percentage uncertainty in the combined carbon stocks and GHG sources in the baseline scenario in stratum i	%
$U_{BSL,SSn,i}$	Percentage uncertainty for carbon stocks and GHG sources in the baseline scenario in stratum i ($1,2 \ldots n$ represent different carbon pools and/or GHG sources)	%

[58] Equation 3.1 and 3.2, Volume 4 - 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Variable	Description	Unit
$\boldsymbol{E_{BSL,SSn,i}}$	Carbon stock or GHG sources in stratum i ($1,2 \ldots n$ represent different carbon pools and/or GHG sources) in the baseline scenario	tCO_2eq
$\boldsymbol{Uncertain_{FCO,i}}$	Percentage uncertainty in the combined carbon stocks and GHG sources in the project scenario in stratum i	%
$\boldsymbol{U_{FCO,SSn,i}}$	Percentage uncertainty for carbon stocks and GHG sources in the project scenario in stratum i ($1,2 \ldots n$ represent different carbon pools and/or GHG sources)	%
$\boldsymbol{E_{FCO,SSn,i}}$	Carbon stock or GHG sources in stratum i ($1,2 \ldots n$ represent different carbon pools and/or GHG sources) in the project scenario	tCO_2eq
$\boldsymbol{i}$	1, 2, 3 … M_{FCO} strata in project scenario 1, 2, 3 …. M_{BSL} strata in baseline scenario	-

Step 2: Assess uncertainty across combined strata

For the baseline scenario:

$$Uncertain_{BSL} = \frac{\sqrt{(U_{BSL,1} \times A_1)^2 + (U_{BSL,2} \times A_2)^2 \ldots + \cdots (U_{BSL,M_{BSL}} \times A_{M_{BSL}})^2}}{\left| A_1 + A_2 \ldots + \cdots A_{M_{BSL}} \right|} \quad (3.3)$$

For the project scenario:

$$Uncertain_{FCO} = \frac{\sqrt{(U_{FCO,1} \times A_1)^2 + (U_{FCO,2} \times A_2)^2 \ldots + \cdots (U_{FCO,M_{FCO}} \times A_{M_{FCO}})^2}}{\left| A_1 + A_2 \ldots + \cdots A_{M_{FCO}} \right|} \quad (3.4)$$

Where:

Variable	Description	Unit
$\boldsymbol{Uncertain_{BSL}}$	Total uncertainty in baseline scenario	%
$\boldsymbol{U_{BSL,i}}$	Uncertainty in baseline scenario in stratum i	%
$\boldsymbol{Uncertain_{FCO}}$	Total uncertainty in project scenario	%
$\boldsymbol{U_{WPS,i}}$	Uncertainty in project scenario in stratum i	%

Variable	Description	Unit
A_i	Area of stratum i	ha

Step 3: Sum up baseline and project uncertainty

$$NER_{ERROR} = \frac{\sqrt{(Uncertain_{BSL} \times GHG_{BSL})^2 + (Uncertain_{FCO} \times GHG_{FCO})^2}}{|GHG_{BSL} + GHG_{FCO}|} \quad (3.5)$$

Where:

Variable	Description	Unit
NER_{ERROR}	Total uncertainty for project activity	%
GHG_{BSL}	Net CO_2eq emissions in the baseline scenario up to year t^*	%
GHG_{FCO}	Net CO_2eq emissions in the project scenario up to year t^*	%

Step 4: Calculate the adjusted net GHG reductions *[59]*

At a 90% confidence interval, the allowable uncertainty is 20% of NER_t.

At a 95% confidence interval, the allowable uncertainty is 30% of NER_t.

Where this precision level is met, the net GHG reductions need not be adjusted to account for the uncertainty.

Where this precision level is not met, the adjusted value for the net GHG reductions to account for uncertainty is calculated as:

$$adj\_NER_t = NER_t \times (100\% - NER_{ERROR} + allow\_unc) \quad (3.6)$$

Where:

Variable	Description	Unit
adj_NER_t	Net GHG emissions reduction in year t adjusted to account for uncertainty	%
NER_t	Total net GHG emissions reductions from the project activity up to year t	%

[59] Section 8.5.2, VM0033 Methodology for Tidal Wetland and Seagrass Restoration

Variable	Description	Unit
$\boldsymbol{allow\_unc}$	Allowable uncertainty At a 90% confidence level = 20% At a 95% confidence level = 30%	%

4 Sample Sizes in Stratified Simple Random Sampling Without Replacement

$N = \frac{A}{AP}\ ; N_i = \frac{A_i}{AP}$ [60] *(4.1)*

Variable	Description	Unit
$\boldsymbol{N}$	Maximum possible number of sample plots in the project area	-
$\boldsymbol{N_i}$	Maximum possible number of sample plots in stratum i	-
$\boldsymbol{A}$	Total size of all strata, e.g., the total project area	ha
$\boldsymbol{A_i}$	Size of each stratum	ha
$\boldsymbol{AP}$	Sample plot size (constant for all strata)	ha

$E_1 = Q_1 \cdot P$ [61] *(4.2)*

Variable	Description	Unit
$\boldsymbol{E_1}$	Allowable error of the estimated quantity Q	-
$\boldsymbol{Q_1}$	Approximate expected value of the estimated quantity Q	-
$\boldsymbol{P}$	Target precision for estimation of Q	-

[60] Equation 1, Calculation of the number of sample plots for measurements within A/R CDM project activities, V02 (UNFCCC)
[61] Equation 2, Calculation of the number of sample plots for measurements within A/R CDM project activities, V02 (UNFCCC)

$$n = \frac{\left[\sum_{i=1}^{L} N_i \cdot st_i\right]^2}{\left(N \cdot \frac{E_1}{z\alpha/_2}\right)^2 + \sum_{i=1}^{M} N_i \cdot (st_i)^2}$$ [62] *(4.3)*

Variable	Description	Unit
n	Sample size (total number of sample plots required) in the project area	-
i	1, 2, 3 … M_{FCO} strata in project scenario	-
α	$1 - \alpha$ is probability that the estimate of the mean is within the error bound E	-
$z\alpha/_2$	Value of the statistic z (embedded in Excel as: inverse of standard normal probability cumulative distribution) For e.g. $1 - \alpha = 0.05$ (implying a 95% confidence level), then $z\alpha/_2 = 1.9599$	-
st_i	Standard deviation of each stratum	
N	Maximum possible number of sample plots in the project area	-
N_i	Maximum possible number of sample plots in stratum i	-
E_1	Allowable error of the estimated quantity Q	-

$$n = \frac{\sum_{i=1}^{L} N_i \cdot st_i}{\left(N \cdot \frac{E_1}{z\alpha/_2}\right)^2 + \sum_{i=1}^{L} N_i \cdot (st_i)^2} \cdot N_i \cdot st_i$$ [63] *(4.4)*

Where:

Variable	Description	Unit
n	Sample size (total number of sample plots required) in the project area	-
i	1, 2, 3 … M_{FCO} strata in project scenario	-

[62] Equation 5, Calculation of the number of sample plots for measurements within A/R CDM project activities, V02 (UNFCCC)
[63] Equation 6, Calculation of the number of sample plots for measurements within A/R CDM project activities, V02 (UNFCCC)

Variable	Description	Unit
α	$1-\alpha$ is probability that the estimate of the mean is within the error bound E	-
$z\alpha/_2$	Value of the statistic z (embedded in Excel as: inverse of standard normal probability cumulative distribution) For e.g. $1-\alpha = 0.05$ (implying a 95% confidence level), then $z\alpha/_2 = 1.9599$	-
st_i	Standard deviation of each stratum	
N	Maximum possible number of sample plots in the project area	-
N_i	Maximum possible number of sample plots in stratum i	-
E_1	Allowable error of the estimated quantity Q	-

4.1 Reference for plot design guide

For further guidance on plot sample design to gather information and assess on carbon stock for forest in Malaysia, project proponent may refer to the Technical Information Handbook No.59- ***Survei Karbon Hutan***. Do note that **Chapter 5** is **not applicable** for FCO program.

For the English summary, kindly refer to Chapter 3 - Plot Design of ***Guide to the Development of Forest Resources Inventory of Sabah.***

<u>Summary</u>

The technical Information Handbook No.59- *Survei Karbon Hutan* serves as a comprehensive field guide for conducting forest carbon surveys in Malaysia. It is designed to support party involved in carbon stock assessments particularly in tropical forest ecosystems. Key components of the manual as follow:

1. Survey Planning and Preparation
2. Field Data Collection Protocols
3. Carbon Estimation Methods
4. Data Management and Quality Control
5. Reporting and Analysis

5 Data and Parameters

5.1 Data and Parameters Monitored

Variables	Description	Unit	Equation
ΔC_{AGB}	Carbon stock in above-ground biomass of tree biomass in baseline and project scenario	tCO2e	1.2.1
ΔC_{BGB}	Carbon stock in below-ground biomass of tree biomass in baseline and project scenario	tCO2e	1.2.2
ΔC_{DW}	Change in carbon stock in dead wood in baseline and project scenario	tCO2e	1.3.1
ΔC_{LI}	Change in carbon stock in litters in baseline and project scenario	tCO2e	1.4.1
ΔC_{SO}	Change in carbon stock in soil in baseline and project scenario	tCO2e	1.5.1
FCi	Consumption of fossil fuel type i for project implementation	Fuel unit	2.1.1

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