SOCIALCARBON®

SCM0008 - Methodology for the Restoration of Mangroves

Document Prepared by the Social Carbon Foundation

Title	Methodology for the Restoration of Mangroves
Version	V1.0

Date of Issue	TBC
Type	Methodology
Sectoral Scope	Scope 14 – Afforestation and Reforestation
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Acknowledgements

We thank the following individuals for their contribution towards the development of this methodology: Divaldo Rezende, Diana Lins, Michael Davies and Raul Feldmann.

Contents

Methodology Details

1. Sources

This methodology uses the following sources:

- SOCIALCARBON Standard v6.0
- SOCIALCARBON Standard Definitions
- AR-AMS0003 – Afforestation and reforestation project activities implemented on wetlands v3.0
- VM0033 – Methodology for Tidal Wetland and Seagrass Restoration, v2.0

Please view the 10. References section of this document to see the full list of sources used to develop this methodology.

2. Summary description of the Methodology

Mangroves are a valuable ecological and economic resource, providing important nursery grounds and breeding sites for birds, fish, crustaceans, shellfish, reptiles and mammals[1]. They offer a number of ecosystem services including, but not limited to, protecting against coastal erosion and carbon sequestration[2]; Mangrove forests are highly productive, with carbon production rates equivalent to tropical humid forests[3].

This methodology provides a means to quantify net GHG emission removals (NERs) from project activities that plant and restore Mangroves.

Additionality and Crediting Method	
Additionality	Project Method
Crediting Baseline	Project Method

[1] Alongi (2001)

[2] Ghosh (2011); Alongi (2002); Bouillon (2008)

[3] Alongi et al. (2012), Mukherjee et al. (2014), Donato et al. (2011)

3. Definitions

In addition to the definitions set out in the latest version of the SOCIALCARBON Standard Definitions, the following definitions apply to this methodology revision:

Allochthonous Soil Organic Carbon
Soil organic carbon originating outside the project area and being deposited in the project area.

Autochthonous Soil Organic Carbon
Soil organic carbon originating or forming in the project area (e.g., from vegetation).

Mangrove
Mangroves are tropical plants that are adapted to loose, wet soils, salt water and being periodically submerged by tides.

Mineral Soil
Soil that is not organic.

Organic Soil
Soil with a surface layer of material that has a sufficient depth and percentage of organic carbon to meet thresholds set by the IPCC (Wetlands supplement) for organic soil. Where used in this methodology, the term peat is used to refer to organic soil.

Salinity
The saltiness or amount of salt dissolved in a body of water, called saline water.

Water Table Depth
Depth of sub-soil or above-soil surface of water, relative to the soil surface

4. Applicability Conditions

This methodology is applicable under the following conditions:

- The land subject to the project activity was historically Mangrove habitat, or within the native geography of Mangrove species[4];

[4] Winterwerp et al. (2020); Chen & Ye (2014); Tachas et al. (2021); Wang et al. (2011) ; Selvam (2007) ; Lee et al. (2019); Kangas (1990); Wilkie et al (2003)

- In strata with organic soil, afforestation, reforestation, and revegetation (ARR) activities must be combined with rewetting;
- Native Mangrove species are planted in the project area[5];
- The project activities either include planting of native Mangrove species or create the conditions required to foster natural regeneration of the existing Mangrove forest in the project area[6].
- Prior to the project start date, the project area:

  a) Is free of any land use that could be displaced outside the project area, as demonstrated by at least one of the following, where relevant:

     i) The project area has been abandoned for two or more years prior to the project start date; or

     ii) Use of the project area for commercial purposes (i.e., trade) is not profitable as a result of salinity intrusion, market forces or other factors. In addition, timber harvesting in the baseline scenario within the project area does not occur; or

     iii) Degradation of additional wetlands for new agricultural sites within the country will not occur or is prohibited by enforced law.

  OR

  b) Is under a land use that could be displaced outside the project area and where degradation of additional mangrove sites for new agricultural/aquacultural sites within the country will not occur or is prohibited by enforced law.

  OR

  c) Is under a land use that will continue at a similar level of service or production during the project crediting period (e.g., subsistence harvesting of firewood).

  The project proponent must demonstrate (a), (b) or (c) above based on verifiable information such as laws and bylaws, management plans, annual reports, annual accounts, market studies, government studies or land use planning reports and documents.

The methodology is not applicable under the following conditions:

- Baseline activities include commercial forestry;

[5] Duke et al. (1998); Ewel (1998)

[6] This includes the deployment of permeable dams to promote rehabilitation (Lovelock et al. (2022); Winterwerp et al. (2020); Lewis III (2005))

- Project activities include the burning of organic soil;
- Nitrogen fertilizer(s), such as chemical fertilizer or manure, are applied in the project area during the project crediting period[7].

5. Project Boundary

5.1 Carbon Pools

The spatial extent of the project boundary encompasses all lands subject to afforestation and/or reforestation of Mangrove forest.

Table 2 below identifies the carbon pools included or excluded from the project boundary.

Table 2: Selected Carbon Pools under Baseline and Project Activity

Carbon Pools	Included?	Explanation
Aboveground woody biomass	Yes	This is a major carbon pool related to the project activity.
Aboveground non-woody biomass	No	Conservatively excluded. Due to the nature of non-woody vegetation that grows within Mangrove forests, there cannot be any guarantee for the 100-year permanence of the carbon pool[8].
Belowground biomass	Yes	This is a major carbon pool related to the project activity.
Deadwood	No	Conservatively excluded.
Litter	No	Litter biomass is subjected to high turnover, displacement due to tidal currents, and consumption by crabs. This carbon pool has been conservatively excluded[9].
Soil Organic Carbon (SOC)	Yes	Optional carbon pool. A key mechanism of Mangroves is their efficiency in trapping sediments and associated carbon from outside their ecosystem boundaries[10].

[7] Romero et al. (2012); Lovelock et al. (2009); Vitousek et al. (1997); Galloway et al. (2004); Reef et al. (2010)

[8] KM & Kumara (2015); Wang et al. (2011)

[9] Adame & Lovelock (2011); Odum (1968); Robertson & Daniel (1989); Rajkaran & Adams (2007); Gong & Ong (1990); Wafar et al. (1997)

[10] Rosentreter et al. (2018); Kristensen et al. (2008); McKee et al. (2000); Saenger (2002); Alongi (2012); Breithaupt et al. (2012); Krauss et al. (2003); Sasmito et al. (2020); Alongi (2014)

5.2 GHG Emission Sources

Table 4 presents the GHG sources included or excluded from the Project Boundary in this methodology.

Table 4 – GHG Sources included in or excluded from the Project Boundary

Source		Gas	Included?	Rationale
Project Emissions	The production of methane by microbes	CO_2	No	Not applicable
		CH_4	Yes	Major emission source to be considered if Soil Organic Carbon is a carbon pool measured by the project[11]
		N_2O	No	Not applicable

Due to the nature of the project activities eligible under this methodology and the land type suitable for project implementation, emissions from fossil fuel combustion are considered negligible[12].

This methodology exclusively quantifies net carbon removals. To ensure conservatism all baseline emissions are considered zero.

5.3 Sea level rise

Sea level rise is a major potential climate change threat to mangrove ecosystems; mangroves are sensitive to changes in inundation duration and frequency as well as salinity levels that exceed a species-specific physiological threshold of tolerance[13]. Increases in flooding duration can lead to plant death at the seaward mangrove margins as well as shifts in species composition[14], ultimately leading to a reduction in productivity and ecosystem services. Whilst some studies indicate that mature mangroves appear to be resilient to sea level rise, this methodology conservatively assumes that the carbon stocks from aboveground biomass are lost to oxidation following submergence with the carbon being immediately and entirely returned to the atmosphere.

When defining geographic project boundaries and strata, the project proponent must consider expected relative sea level rise and the potential for expanding the project area landward to account for mangrove forest migration, inundation and erosion. The project area cannot be changed during the project crediting period.

For both the baseline and project scenarios, the project proponent must provide a projection of relative sea level rise within the project area based on IPCC regional forecasts or peer-reviewed literature applicable to

[11] Rosentreter et al. (2018); Arai et al. (2021); Conrad (2005); Conrad (1999);

[12] Manual planting is the most common practice: UNDP (2017); Rodríguez-Rodríguez et al. (2021)

[13] Ball (1988); Friess et al. (2012)

[14] He et al. (2007); Gilman et al. (2008); Castañeda-Moya et al. (2013)

the region. In addition, the project proponent may also utilise expert judgment[15]. Global average sea level rise scenarios are not suitable for determining the changes in wetlands boundaries. Therefore, if used, IPCC most-likely global sea level rise scenarios must be appropriately downscaled to regional conditions that include vertical land movements, such as subsidence.

The assessment of potential mangrove migration, inundation and erosion with respect to projected sea level rise must account for topographical slope, land use and management, sediment supply and tidal range. The assessment may use published data from the project area, expert judgment or both.

When assessing the potential for mangroves to migrate horizontally, one must consider the topography of the adjacent land and any migration barriers that may exist. In general, and on coastlines where mangroves migration is unimpaired by infrastructure, concave-up slopes may cause 'coastal squeeze', while straight or convex-up gradients are more likely to provide the space required for lateral movement.[16]

For areas that submerge the loss of SOC may be assumed to be insignificant in the project scenario. The projection of mangrove boundaries within the project area must be presented in maps delineating these boundaries from the project start date until the end of the project crediting period, at intervals appropriate to the rate of change due to sea level rise, and at t = 100.

Procedures for accounting for project area submergence due to relative sea level rise are provided in section 8.5 Accounting for Sea level rise.

6. Baseline Scenario

The baseline scenario shall be established according to the most recent version of the "Tool for the Demonstration and Assessment of Additionality in SOCIALCARBON Agriculture, Forestry and Other Land Use (AFOLU) Project Activities" (SCT0001)[17].

7. Additionality

This methodology uses a project method for the demonstration of additionality.

Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the SOCIALCARBON Methodology Requirements.

Step 2: Project Method

[15] Requirements for expert judgment are provided in Section 9.3.7.

[16] Sadat-Noori et al., (2021)

[17] SCT0001. Tool for the Demonstration and Assessment of Additionality in SOCIALCARBON Agriculture, Forestry and Other Land Use (AFOLU) Project Activities. Available at: https://www.socialcarbon.org/sct0001.

The project activity shall apply the additionality analysis method set out in the latest version of the *SOCIALCARBON Tool for the Demonstration and Assessment of Additionality for AFOLU project activities (SCT0001)* to determine that the proposed project activity is additional.

8. Quantification of GHG Emission Removals

8.1 Baseline Emissions

Emissions in the baseline scenario shall be conservatively set to zero.

8.2 Baseline removals

If no Mangroves are present in the project area the baseline carbon removals shall be considered zero.

$$C_{BSL,t} = C_{AGB_{BSL,t}} + C_{BGB_{BSL,t}} + C_{Soil_{BSL,t}} \quad \text{(Equation 1)}$$

Where:

$C_{BSL,t}$	=	Baseline net GHG carbon stocks by sinks in year t; tCO_2e
$C_{AGB_{BSL,t}}$	=	Baseline carbon stock from aboveground mangrove biomass within the project boundary in year t; tCO_2e
$C_{BGB_{BSL,t}}$	=	Baseline carbon stock from belowground mangrove biomass within the project boundary in year t
$C_{Soil_{BSL,t}}$	=	Baseline Soil Organic Carbon stock within the project boundary in year t; tCO_2e

8.2.1 Aboveground and belowground woody biomass of mangrove trees

If carbon stocks in aboveground and belowground woody biomass are included in the project boundary, the aboveground carbon stocks ($C_{AGB_{BSL}}$) and belowground carbon stocks ($C_{BGB_{BSL}}$) in the baseline for sample unit i are calculated using the latest version of the CDM Tool "*AR-Tool14 Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities".*

Project Proponents are permitted to utilise emerging technology (e.g. remote sensing) with known uncertainty to measure changes in carbon stocks for the class of vegetation cover. These emerging technology approaches must be supported by peer-reviewed literature which validates their accuracy and uncertainty. Justification for the chosen approach should be documented in the Project Description Document supplemented with appropriate evidence. Any uncertainty in the approach used must be discounted for. All parameters, data sources and assumptions applied by the emerging technology must be documented in the Project Description Document.

8.2.2 Soil Organic Carbon

$$C_{Soil_{BSL,t}} = A_{i,t} \times (C_{Soil,i,t} - C_{Soil\_Alloch,i,t}) \quad \text{(Equation 2)}$$

Where:

$C_{Soil_{BSL,t}}$	=	Baseline Soil Organic Carbon stock within the project boundary in year t; tCO_2e
$A_{i,t}$	=	Area of baseline stratum i (in year t); ha
$C_{Soil,i,t}$	=	Baseline Soil Organic Carbon stock within the project boundary in stratum i in year t; $tCO_2e\ ha^{-1}$
$C_{Soil\_Alloch,i,t}$	=	Deduction from the SOC pool to account for the percentage of the carbon stock that is derived from allochthonous soil organic carbon; $tCO_2e\ ha^{-1}$

Soil Organic Carbon stocks shall be measured in line with the requirements outlined in section **9.3.4 Soil core approach to estimating soil carbon** Allochthonous soil organic carbon may accumulate in the project area, and such carbon must be accounted for in the project scenario. Procedures for the estimation of a compensation factor for allochthonous soil organic carbon are specified in Section 8.2.3.

8.2.3 Deduction for allochthonous carbon

The determination of the deduction for allochthonous carbon[18] is mandatory for the project scenario unless the project proponent is able to demonstrate that the allochthonous carbon would have been returned to the atmosphere in the form of carbon dioxide in the absence of the project.

The deduction for allochthonous carbon must only be applied to soil layers deposited or accumulated after the project start date (such as materials formed above a feldspar marker horizon).

If the organic surface layer exceeds 10 cm, the soil is deemed organic, and no deduction is required. If an organic surface layer of up to 10 cm is present, $\%\mathrm{Allochthonous}_{SOC_{i,t}}$ must be determined only in such cases where the project experiences mineral sedimentation events sufficient to create mineral soil layers. In practice, the project area may show mineral sedimentation in places. If this is observed, it is assumed that at some point during the project crediting period mineral sediment can be deposited on top of organic

[18] Ranjan et al. (2011), Stringer et al. (2016), Xiong et al. (2018)

surface layers unless the project proponent can justify that strata with an organic surface layer of less than 10 cm will not experience mineral sedimentation during the project crediting period.

$$C_{Soil\_Alloch,i,t} = C_{Soil,i,t} \times \%C_{alloch} \quad \text{(Equation 3)}$$

Where:

$C_{Soil\_Alloch,i,t}$	=	Deduction from the SOC pool to account for the percentage of the carbon stock that is derived from allochthonous soil organic carbon; $tCO_2e\ ha^{-1}$
$\%C_{alloch}$	=	Percentage of the total soil organic carbon that is allochthonous; %
$C_{Soil,i,t}$	=	Baseline Soil Organic Carbon stock within the project boundary in stratum i in year t; $tCO_2e\ ha^{-1}$

$C_{Soil\_Alloch,i,t}$ may be conservatively set to zero in the baseline scenario.

$\%C_{alloch}$ may be estimated using either:

1. Published values
2. Field-collected data
3. Modelling

Published values

Peer-reviewed published data may be used to generate a value of the percentage of allochthonous soil organic carbon in the same or similar systems as those in the project area based on the guidelines described in Section **9.3.4 Soil core approach to estimating soil carbon**.

For example, Needelman et al. (2018) provide a value for the percentage of the total soil organic carbon that is allochthonous ($\%C_{alloch}$) based on the percentage soil carbon, which can be used for mangroves with mineral soils.

Field-collected data

For this method, the allochthonous carbon percentage is estimated using default values (listed below) and measured through analysis of field-collected soil cores (for soil carbon or organic matter).

For the following equation, $\%C_{soil}$ may be measured directly or derived from $\%OM_{soil}$ using the equations in Section **9.3.4 Soil core approach to estimating soil carbon**. $\%C_{autoch}$ is derived from $\%OM_{autoch}$ (defined below) using the equations in Section **9.3.4 Soil core approach to estimating soil carbon**.

$$\%C_{alloch} = 100 \times \frac{(\%C_{soil} - \%C_{autoch})}{\%C_{soil}} \quad \text{(Equation 4)}$$

Where:

$\%C_{autoch}$	=	Percentage of the total soil organic carbon that is allochthonous; %
$\%C_{alloch}$	=	Percentage of the total soil organic carbon that is allochthonous; %
$\%C_{soil}$	=	Percentage of soil that is organic carbon; %

For the following equation, $\%OM_{soil}$ may be estimated directly using loss-on-ignition (LOI) data or indirectly from $\%C_{soil}$ using the equations below. $\%OM_{depsed}$ may be estimated directly using loss-on-ignition (LOI) data, indirectly from $\%OM_{soil}$ using the equations below, or by using the default value given below.

$$\%OM_{autoch} = \frac{\%OM_{soil} - \%OM_{depsed}}{1 - \%OM_{depsed}} \quad \text{(Equation 5)}$$

Where:

$\%OM_{autoch}$	=	Percentage of soil that is autochthonous organic matter; %
$\%OM_{depsed}$	=	Percentage of deposited sediment that is organic matter; %
$\%OM_{soil}$	=	Percentage of soil that is soil organic matter; %

The following equations may be used to derive $\%OM_{soil}$ from $\%C_{soil}$ and $\%OM_{depsed}$ from $\%C_{depsed}$, respectively[19]. Alternatively, an equation developed using site-specific data may be used or an equation from peer-reviewed literature may be used if the equation represents soils from the same or similar systems as those in the project area.

$$\%OM_{soil} = \frac{(\%C_{soil} - 2.8857)}{0.415} \quad \text{(Equation 6)}$$

$$\%OM_{depsed} = \frac{(\%C_{depsed} - 2.8857)}{0.415} \quad \text{(Equation 7)}$$

[19] Kauffman et al. (2011); Howard et al. (2014)

In all cases, the following default factor[20] may be used for the determination of $\%OM_{depsed}$:

$$\%OM_{depsed} = 1.5$$

Alternatively, $\%C_{depsed}$ may be calculated as:

$$\%C_{depsed} = 0.086 \times SA + 0.05 \quad \text{(Equation 8)}$$

Where:

SA	=	Average Surface Area of the sediment; m^2g^{-1}

8.3 Project Emissions

8.3.3 The production of methane by microbes

Organic matter burial in mangrove forests results in the removal and long-term storage of atmospheric CO_2. However, some of this organic matter is metabolized and returned to the atmosphere as CH_4[21]. Two approaches can be used to account for methane production: direct measurement and default discount value.

Direct measurement

Direct measurement of CH_4 shall be calculated in line with the requirements documented in Section **9.3.5 Monitoring CH4 emissions**.

$$E_{Soil,CH4,i,t} = E_{CH4-daily,i,t} \times 365 \times GWP_{CH4} \times 100 \quad \text{(Equation 9)}$$

Where:

$E_{Soil,CH4,i,t}$	=	CH_4 emissions from the SOC pool in the project scenario in stratum i in year t; tCO_2e
$E_{CH4-daily,i,t}$	=	Average daily CH_4 emissions in the baseline scenario based on direct measurements of stratum i in year t; mg CH_4 m^{-2} d^{-1}

[20] Mayer 1994

[21] Rosentreter et al. (2018); Kristensen et al. (2008); McKee et al. (2000); Saenger (2002); Alongi (2012); Breithaupt et al. (2012); Krauss et al. (2003); Sasmito et al. (2020); Alongi (2014)

365	=	Conversion of daily value to year
GWP_{CH4}	=	Global Warming Potential of CH_4 (the latest IPCC GWP value for 100-year time horizon must be used).
t	=	1, 2, 3, … t* years elapsed since the project start date; years
i	=	1, 2, 3 …M_{WPS} strata in the project scenario
100	=	Conversion factor of mg m^{-2} to tonne ha^{-1}

Default discount value

If Soil Organic Carbon (SOC) removals are quantified by the project, a default discount value can be applied to the estimated SOC removals during the monitoring period. Rosentreter et al. (2018) show that high CH_4 evasion rates have the potential to partially offset blue carbon burial rates in mangrove sediments using the 20-year and 100-year global warming potential of CH_4.

Instead of direct measurement of methane emissions, project proponents are permitted to apply a discount rate of 10%[22] to their measured net SOC removal measured in the monitoring period.

8.4 Project Removals

Project proponents should use the following equations to quantify the project removals achieved.

$$TER_t = \Delta TC_{PS,t} - \Delta TC_{BSL,t} \quad \text{(Equation 10)}$$

Where:

TER_t	=	Total Emission Removals in year t; tCO_2e
$\Delta TC_{\mathrm{PS},t}$	=	Total change in carbon stocks in the project scenario in monitoring period t; tCO_2e
$\Delta TC_{\mathrm{BSL},t}$	=	Total change in carbon stocks in the baseline scenario in monitoring period t; tCO_2e

$$\Delta TC_t = \Delta C_{AGB_t} + \Delta C_{BGB_t} + \Delta C_{Soil_t} \quad \text{(Equation 11)}$$

[22] Value conservatively rounded up to 10% using the highest measured methane emission offset (9.3%) calculated by Rosentreter et al. (2018)

Where:

ΔTC_t	=	Change in in total carbon stocks within the project boundary in monitoring period t; tCO_2e
ΔC_{AGB_t}	=	Change in carbon stocks from aboveground mangrove biomass within the project boundary in monitoring period t; tCO_2e
ΔC_{BGB_t}	=	Change in carbon stocks from belowground mangrove biomass within the project boundary in monitoring period t; tCO_2e
ΔC_{Soil_t}	=	Change in Soil Organic carbon stocks within the project boundary in monitoring period t; tCO_2e

ΔC_{AGB_t}, ΔC_{BGB_t} and ΔC_{Soil_t} should be calculated in line with the procedures outlined in Section 8.2 Baseline removals.

For strata where reforestation or revegetation activities include harvesting, the long-term carbon average of C_{AGB} must be calculated as specified in Section 8.2 Baseline removals.

8.5 Accounting for Sea level rise

The consequences of submergence of a given stratum due to sea level rise are:

1) Carbon stocks from aboveground biomass are lost to oxidation, and

2) Depending upon the geomorphic setting, soil carbon stocks may be held intact or be transported beyond the project area. It is assumed that all carbon is re-sedimented and stored (and not oxidized).[23]

For strata where conversion to open water is expected before t = 100, the maximum quantity of GHG emission removals that may be claimed by the project must be calculated as defined below. Regarding (1) above, where biomass is submerged, it is assumed that this carbon is immediately and entirely returned to the atmosphere. For such strata:

$$\Delta C_{AGB,i,t} = C_{AGB,i,t} - C_{AGB,i,t-1} \quad \text{(Equation 12)}$$

For the year of submergence:

$$C_{AGB,i,t} = 0$$

Where:

[23] Poffenbarger et al. (2011)

$\Delta C_{AGB,i,t}$	=	Net change in Carbon Stocks in Aboveground Biomass in stratum i at the year t of submergence; tCO_2e
$C_{AGB,i,t}$	=	Carbon Stocks in Aboveground Biomass in stratum i at the year t of submergence; tCO_2e
$C_{AGB,i,t-1}$	=	Carbon Stocks in Aboveground Biomass in stratum i at the year prior to submergence; tCO_2e
t	=	1, 2, 3, … t* years elapsed since the project start date; years
i	=	Stratum of the mangrove forest submerged

The gradual loss of vegetation in the project area due to submergence may be captured by detailed stratification into areas with and without vegetation.

The loss of carbon stocks resulting from sea level rise must be used to calculate the long-term net benefit of the projects. See Appendix 2: Calculating the Long Term Net Carbon Benefit for more details.

8.6 Leakage

8.6.1 Activity-shifting leakage and market leakage

The applicability conditions of this methodology are structured to ensure that activity-shifting leakage and market leakage do not occur. As such, where the applicability conditions of this methodology are met, activity-shifting leakage and market leakage may be assumed to be zero.

8.6.2 Ecological leakage

It may be assumed that ecological leakage does not occur; the nature of the project activities and applicability conditions means that ecological leakage may be assumed to be zero.

8.7 Uncertainty

The following procedure allows the project proponent to estimate uncertainty in the estimation of emissions and carbon stock changes (i.e., for calculating a precision level and any deduction in credits for lack of precision following project implementation and monitoring) by assessing uncertainty in baseline and project estimations.

This procedure focuses on the following sources of uncertainty:

- Uncertainty associated with estimation of stocks in carbon pools and changes in carbon stocks
- Uncertainty in assessment of project emissions

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

8.7.1 Uncertainty guidance

A precision target of a 90% or 95% confidence interval equal to or less than 20% or 30%, respectively, of the recorded value must be targeted. This is especially important in terms of project planning for measurement of carbon stocks where sufficient measurement plots should be included to achieve this precision level across the measured stocks.

Levels of uncertainty must be known for all aspects of baseline and project implementation and monitoring. Uncertainty will generally be known as the 90% or 95% confidence interval expressed as a percentage of the mean. Where uncertainty is not known, it must be demonstrated that the value used is conservative.

Estimated carbon emissions and removals arising from AFOLU activities have uncertainties associated with the measures and estimates of several parameters. These include the project area or other activity data, carbon stocks, biomass growth rates, expansion factors and other coefficients. It is assumed that the uncertainties associated with the estimates of the various input data are available, either as default factors given in IPCC Guidelines (2006), IPCC GPGLULUCF (2003), expert judgment or estimates based of sound statistical sampling.

Alternatively, conservative estimates may also be used instead of uncertainties, provided that they are based on verifiable literature sources or expert judgment. In this case the uncertainty is assumed to be zero. However, these procedures combine uncertainty information and conservative estimates resulting in an overall ex-post project uncertainty.

8.7.2 Planning to diminish uncertainty

It is important that the process of project planning consider uncertainty. Procedures including stratification and the allocation of sufficient measurement plots help ensure that low uncertainty in carbon stocks results and ultimately full crediting can result.

It is good practice to apply this procedure at an early stage to identify the data sources with the highest uncertainty to allow the opportunity to conduct further work to diminish uncertainty.

Note that in Parts 1 – 3 below the denominators of the equations must be expressed in absolute values.

Part 1 – Uncertainty in baseline estimates

$$\text{Uncertainty}_{BSL,i} = \frac{\sqrt{(\text{U}_{BSL,X1,i} \times \text{E}_{BSL,X1,i})^2 + (\text{U}_{BSL,X2,i} \times \text{E}_{BSL,X2,i})^2 + (\text{U}_{BSL,Xn,i} \times \text{E}_{BSL,Xn,i})^2}}{\text{E}_{BSL,X1,i} + \text{E}_{BSL,X2,i} \ldots + .. \text{E}_{BSL,Xn,i}} \quad \text{(Equation 13)}$$

Where:

$\text{Uncertainty}_{BSL,i}$	=	Percentage uncertainty in the combined carbon stocks and GHG sources in the baseline scenario in stratum i; %
$\text{U}_{BSL,X,i}$	=	Percentage uncertainty (expressed as 90% confidence interval as a percentage of the mean, where appropriate) for carbon stocks and GHG sources in the baseline scenario in stratum i (1,2…n represent different carbon pools and/or GHG sources); %
$\text{E}_{BSL,X,i}$	=	Carbon stock or GHG sources (e.g., trees, down dead wood) in stratum i (1,2…n represent different carbon pools and/or GHG sources) in the baseline scenario; tCO_2e
i	=	1, 2, 3 … strata in the baseline scenario

To assess uncertainty across combined strata, use the equation below:

$$Uncertainty_{BSL} = \frac{\sqrt{(U_{BSL,1} \times A_1)^2 + (U_{BSL,2} \times A_2)^2 + (U_{BSL,n} \times A_n)^2}}{A_1 + A_2 ... + .. A_n}$$ (Equation 14)

Where:

$Uncertainty_{BSL}$	=	Total uncertainty in the baseline scenario; %
$U_{BSL,i}$	=	Uncertainty in baseline scenario in stratum i; %
A_i	=	Area of stratum i; h

Part 2 – Uncertainty ex-post in the project scenario

$$Uncertainty_{P,i} = \frac{\sqrt{(U_{PS,X1,i} \times E_{PS,X1,i})^2 + (U_{PS,X2,i} \times E_{PS,X2,i})^2 + (U_{PS,Xn,i} \times E_{PS,Xn,i})^2}}{E_{PS,X1,i} + E_{PS,X2,i} ... + .. E_{PS,Xn,i}}$$ (Equation 15)

Where:

$Uncertainty_{PS,i}$	=	Percentage uncertainty in the combined carbon stocks and GHG sources in the project scenario in stratum i; %
$U_{PS,X,i}$	=	Percentage uncertainty (expressed as 90% confidence interval as a percentage of the mean, where appropriate) for carbon stocks and GHG sources in the project scenario in stratum i (1,2…n represent different carbon pools and/or GHG sources); %
$E_{PS,X,i}$	=	Carbon stock or GHG sources (e.g., trees, down dead wood) in stratum i (1,2…n represent different carbon pools and/or GHG sources) in the project scenario; tCO_2e
i	=	1, 2, 3 … strata in the project scenario

To assess uncertainty across combined strata, use the equation below:

$$Uncertainty_{PS} = \frac{\sqrt{(U_{PS,1} \times A_1)^2 + (U_{PS,2} \times A_2)^2 + (U_{PS,n} \times A_n)^2}}{A_1 + A_2 ... + .. A_n}$$ (Equation 16)

Where:

$Uncertainty_{PS}$	=	Total uncertainty in the project scenario; %
$U_{PS,i}$	=	Uncertainty in project scenario in stratum i; %
A_i	=	Area of stratum i; h

Part 3 – Total error in project activity

$$NER_{ERROR} = \frac{\sqrt{(Uncertainty_{BSL} \times GHG_{BSL})^2 + (Uncertainty_{PS} \times GHG_{PS})^2}}{GHG_{BSL} + GHG_{PS}}$$ (Equation 17)

Where:

NER_{ERROR}	=	Total uncertainty for project activity; %
Uncertainty_{BSL}	=	Total uncertainty in baseline scenario; %
Uncertainty_{PS}	=	Total uncertainty in project scenario; %
GHG_{BSL}	=	Net CO2e emissions in the baseline scenario in the monitoring period t; tCO_2e
GHG_{PS}	=	Net CO2e emissions in the project scenario in the monitoring period t; tCO_2e

The allowable uncertainty is 20% or 30% of NER_t at a 90% or 95% confidence level, respectively. Where this precision level is met, no deduction must result for uncertainty. Where this precision level is exceeded, a deduction equal to the amount that the uncertainty exceeds the allowable level must be applied. The adjusted value for NER_t to account for uncertainty must be calculated as:

$$\text{Adjusted\_NER}_t = \text{NER}_t \times (100\% - \text{NER}_{ERROR} + allowable\_uncertainty) \quad \text{(Equation 18)}$$

Where:

Adjusted_NER_t	=	Total uncertainty for project activity; %
NER_t	=	Total net GHG emission removals from the project activity in the monitoring period t; t CO2e
NER_{ERROR}	=	Total uncertainty in project scenario; %
$allowable\_uncertainty$	=	Allowable uncertainty; 20% or 30% at a 90% or 95% confidence level, respectively; %

8.8 Net GHG Emission Removals

Net GHG emission removals are calculated by deducting the calculated Buffer amount from the Total Emission Removals calculated using equation 19.

$$NER_t = TER_t - PE_t - BUFFER_t \quad \text{(Equation 19)}$$

Where:

NER_t	=	Net emission removals during monitoring period t; tCO_2e
TER_t	=	Total emission removals during monitoring period t; tCO_2e
PE_t	=	Total project emissions during monitoring period t; tCO_2e

$BUFFER_t$	=	The number of Buffer credits to be deducted during monitoring period t; tCO_2e, calculated by $TER_t \times Non - Permanence\ Risk\ Score\ (\%)$; tCO_2e

Where uncertainty has been calculated the Net emission removals shall be calculated as follows:

$$NER_t = (Adjusted\_NER_t - Adjusted\_NER_{t-1}) - BUFFER_t \quad \text{(Equation 20)}$$

9. Monitoring

Where discretion exists in the selection of a value for a parameter, the principle of conservativeness must be applied.

9.1 Data and Parameters Available at Validation

Data / Parameter	$C_{BSL,t}$
Data unit	tCO_2e
Description	Baseline net GHG carbon stocks by sinks in year t
Equations	1
Source of data	Derived from application of AR-Tool14
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$C_{AGB_{BSL,t}}$

Data unit	tCO_2e
Description	Baseline carbon stock from aboveground mangrove biomass within the project boundary in year t
Equations	1
Source of data	Derived from application of AR-Tool14
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$C_{BGB_{BSL,t}}$
Data unit	tCO_2e
Description	Baseline carbon stock from belowground mangrove biomass within the project boundary in year t
Equations	1
Source of data	Derived from application of AR-Tool14
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$C_{Soil_{BSL,t}}$
Data unit	tCO_2e
Description	Baseline Soil Organic Carbon stock within the project boundary in year t
Equations	1, 2
Source of data	Measured according to Section **9.3.4 Soil core approach to estimating soil carbon**
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	For the baseline scenario, soil cores must be collected within 2 years prior to the project start date.
Purpose of Data	Calculation of baseline carbon stocks
Comments	Reassessed when baseline is reassessed

Data / Parameter	$Depth_{Soil,I,t0}$
Data unit	m
Description	Soil depth in stratum i at the project start date
Equations	22
Source of data	Direct measurements in the project area.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Mineral soil depths at the project start date shall be derived from direct measurements within the project area.
Purpose of Data	Calculation of baseline carbon stocks
Comments	NA

Data / Parameter	A_i
Data unit	ha
Description	Area of stratum i
Equations	2, 14
Source of data	Delineation of strata is done preferably using a Geographical Information System (GIS), which allows for integrating data from different sources (including GPS coordinates and remote sensing data). Applied techniques must follow international standards of application or local standards as laid out in pertinent scientific literature or handbooks.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Source of data above
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$C_{Soil,i,t}$
Data unit	tCO_2e ha^{-1}
Description	Baseline Soil Organic Carbon stock within the project boundary in stratum i in year t
Equations	2, 3
Source of data	Measured according to Section **9.3.4 Soil core approach to estimating soil carbon**
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Section **9.3.4 Soil core approach to estimating soil carbon**
Purpose of Data	Calculation of baseline carbon stocks

Comments	N/A

Data / Parameter	CF_{SOC_sample}
Data unit	Percentage
Description	Carbon fraction of the sample, as determined in laboratory
Equations	22
Source of data	Measured according to Section **9.3.4 Soil core approach to estimating soil carbon**
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Section **9.3.4 Soil core approach to estimating soil carbon**
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	BD
Data unit	g cm^{-3}
Description	Bulk density, as determined in laboratory (Dry bulk density)
Equations	22
Source of data	Direct measurements, or from a relationship with organic carbon content provided by the scientific literature.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Mass of soil material after drying per volume of soil material, based on commonly accepted procedures by the scientific community. See Section **9.3.4 Soil core approach to estimating soil carbon**
Purpose of Data	Calculation of baseline carbon stocks

Comments	N/A

Data / Parameter	$Thickness$
Data unit	cm
Description	Thickness of soil horizon based of subdivisions of soil cores
Equations	22
Source of data	Measured according to Section **9.3.4 Soil core approach to estimating soil carbon**
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Section **9.3.4 Soil core approach to estimating soil carbon**
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$Ndepth$
Data unit	Dimensionless
Description	Number for soil horizons, based on subdivisions of soil cores
Equations	22
Source of data	Measured according to Section **9.3.4 Soil core approach to estimating soil carbon**
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Section **9.3.4 Soil core approach to estimating soil carbon**
Purpose of Data	Calculation of baseline carbon stocks

Comments	N/A

Data / Parameter	$\%C_{alloch}$
Data unit	Percentage
Description	Percentage of the total soil organic carbon that is allochthonous
Equations	3, 4
Source of data	$\%C_{alloch}$ may be estimated using either: 1. Published values 2. Field-collected data 3. Modelling Needelman et al. (2018) provide a value for the percentage of the total soil organic carbon that is allochthonous ($\%C_{alloch}$) based on the percentage soil carbon, which can be used for mangroves with mineral soils.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See section 8.2.3
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$C_{Soil\_Alloch,i,t}$
Data unit	tCO_2e ha^{-1}
Description	Deduction from the SOC pool to account for the percentage of the carbon stock that is derived from allochthonous soil organic carbon
Equations	2, 3

Source of data	Calculated based on measured Baseline Soil Organic Carbon stock and percentage of the total soil organic carbon that is allochthonous
Value applied	N/A $C_{Soil\_Alloch,i,t}$ may be conservatively set to zero in the baseline scenario.
Justification of choice of data or description of measurement methods and procedures applied	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$\%C_{soil}$
Data unit	Percentage
Description	Percentage of soil organic C
Equations	4, 6
Source of data	Direct measurements or may be derived from direct measurements of soil organic matter. These measurements may be made using samples collected in Section **9.3.4 Soil core approach to estimating soil carbon** or indirectly from the soil carbon percentage as described in Section 8.2.3.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See Section **9.3.4 Soil core approach to estimating soil carbon**
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$\%C_{autoch}$

Data unit	Percentage
Description	Percentage of the total soil organic carbon that is allochthonous
Equations	4
Source of data	Measured through field-collected data
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See section 8.2.3
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$\%OM_{soil}$
Data unit	Percentage
Description	Percentage of soil that is organic matter
Equations	5, 6
Source of data	Direct measurements based on loss-on-ignition or may be derived from direct measurements of soil carbon. These measurements may be made using samples collected in Section **9.3.4 Soil core approach to estimating soil carbon** or indirectly from the soil carbon percentage as described in Section 8.2.3.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The equation provided in section 8.2.3 was developed by Kauffman et al. 2011
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$\%OM_{depsed}$
Data unit	Percentage
Description	Percentage of deposited sediment that is organic matter
Equations	5, 7, 8
Source of data	Direct measurements based on loss-on-ignition or may be derived from direct measurements of soil carbon. These measurements may be made using samples collected in Section **9.3.4 Soil core approach to estimating soil carbon** or indirectly from the soil carbon percentage as described in Section 8.2.3.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	LOI may be assessed using standard laboratory procedures, see Section **9.3.4 Soil core approach to estimating soil carbon**. In all cases, a default factor of 1.5% may be applied based on Mayer (1994)
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$\%OM_{autoch}$
Data unit	Percentage
Description	Percentage of soil that is autochthonous organic matter
Equations	5
Source of data	Determined based on the values applied for $\%OM_{soil}$ and $\%OM_{depsed}$
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	See section 8.2.3

Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	$\%C_{depsed}$
Data unit	Percentage
Description	Percentage of deposited sediment that is organic C
Equations	7, 8
Source of data	May be estimated directly using loss-on-ignition (LOI) data or indirectly from soil carbon percentage as described in Section 8.2.3. These measurements may be made using samples collected on sediment tiles or through collection and carbon analysis (see Section **9.3.4 Soil core approach to estimating soil carbon**)
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The default factor is derived from the maximum value (conservative) provided by Mayer 1994 Figure 4
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

Data / Parameter	allowable_uncertainty
Data unit	Percentage
Description	Allowable uncertainty; 20% or 30% at a 90% or 95% confidence level, respectively
Equations	18
Source of data	N/A
Value applied	N/A

Justification of choice of data or description of measurement methods and procedures applied	N/A
Purpose of Data	Calculation of baseline carbon stocks
Comments	N/A

9.2 Data and Parameters Monitored

For all equations used for the calculation of baseline emissions where the subscript BSL is used, these must be substituted by PS and applied to the project scenario. For data and parameters used for the calculation of baseline removals listed in Section 9.1 Data and Parameters Available at Validationabove that are also monitored in the project scenario, the frequency of monitoring/recording is at each monitoring period, and QA/QC procedures to be applied are provided in Section **9.3.6 Uncertainty and quality management**.

Data / Parameter:	ΔC_{AGB_t}
Data unit:	tCO_2e
Description:	Change in carbon stocks from aboveground mangrove biomass within the project boundary in monitoring period t
Equations	11, 12
Source of data:	Derived from application of AR-Tool14
Description of measurement methods and procedures to be applied:	See AR-Tool14
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculation of project removals

Calculation method:	N/A
Comments:	N/A

Data / Parameter:	ΔC_{BGB_t}
Data unit:	tCO_2e
Description:	Change in carbon stocks from belowground mangrove biomass within the project boundary in monitoring period t
Equations	11
Source of data:	Derived from application of AR-Tool14
Description of measurement methods and procedures to be applied:	See AR-Tool14
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	9.3.7
Purpose of data:	Calculation of project removals
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	ΔC_{Soil_t}
Data unit:	tCO_2e
Description:	change in Soil Organic carbon stocks within the project boundary in monitoring period t
Equations	11
Source of data:	Measured according to Section **9.3.4 Soil core approach to estimating soil carbon**

Description of measurement methods and procedures to be applied:	See Section **9.3.4 Soil core approach to estimating soil carbon**
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**.
Purpose of data:	Calculation of project removals
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$A_{i,t}$
Data unit:	hectares
Description:	Area of project stratum i (in year t)
Equations	2
Source of data:	Delineation of strata must be done preferably using a Geographical Information System (GIS), which allows for integrating data from different sources (including GPS coordinates and Remote Sensing data)
Description of measurement methods and procedures to be applied:	See source of data above
Frequency of monitoring/recording:	At each monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculation of net emission removals
Calculation method:	See source of data above

Comments:	N/A

Data / Parameter:	$\%OM_{soil}$
Data unit:	Percentage
Description:	Percentage of soil that is organic matter
Equations	5, 6
Source of data:	Direct measurements based on loss-on-ignition or may be derived from direct measurements of soil carbon. These measurements may be made using samples collected in Section 9.3.4 or indirectly from the soil carbon percentage as described in Section 8.2.3. The equations provided were developed by Kauffman et al. 2011
Description of measurement methods and procedures to be applied:	See Section **9.3.4 Soil core approach to estimating soil carbon** and Section 8.2.3
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculation of change in Soil Organic Carbon
Calculation method:	See source of data above
Comments:	N/A

Data / Parameter:	$\%C_{soil}$
Data unit:	Percentage
Description:	Percentage of soil organic C
Equations	4, 6
Source of data:	Direct measurements or may be derived from direct measurements of soil organic matter. These measurements may be made using samples

	collected in Section **9.3.4 Soil core approach to estimating soil carbon** or indirectly from the soil carbon percentage as described in Section 8.2.3.
Description of measurement methods and procedures to be applied:	See Section **9.3.4 Soil core approach to estimating soil carbon** and Section 8.2.3
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculation of change in Soil Organic Carbon
Calculation method:	See source of data above
Comments:	N/A

Data / Parameter:	Crown cover, vegetation cover
Data unit:	Percentage
Description:	Proportion of an area covered by the herbaceous vegetation, shrubs, and/or the crowns of live trees
Equations	N/A
Source of data:	For the project scenario, crown or vegetation cover mapping must be performed according to established methods in scientific literature.
Description of measurement methods and procedures to be applied:	See CDM Tool “AR-Tool14 Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities”.
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculation of change in woody biomass

Calculation method:	See source of data above
Comments:	N/A

Data / Parameter:	BD
Data unit:	g cm^{-3}
Description:	Dry bulk density
Equations	22
Source of data:	Direct measurements, or from a relationship with organic carbon content provided by the scientific literature.
Description of measurement methods and procedures to be applied:	Mass of soil material after drying per volume of soil material, based on commonly accepted procedures by the scientific community
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculation of change in Soil Organic Carbon
Calculation method:	See source of data above
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$\%C_{depsed}$
Data unit:	Percentage
Description:	Percentage of carbon in deposited sediment
Equations	7, 9

Source of data:	May be estimated directly using loss-on-ignition (LOI) data or indirectly from soil carbon percentage as described in Section 8.2.3. These measurements may be made using samples collected on sediment tiles or through collection and carbon analysis (see Section **9.3.4 Soil core approach to estimating soil carbon**)
Description of measurement methods and procedures to be applied:	The default factor is derived from the maximum value (conservative) provided by Mayer 1994 Figure 4
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See source of data above
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	NER_{ERROR}
Data unit:	Percentage
Description:	Total uncertainty for project activity
Equations	17, 18
Source of data:	N/A
Description of measurement methods and procedures to be applied:	See Section 8.7 Uncertainty
Frequency of monitoring/recording:	At every monitoring period

QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculation of net GHG emission removals
Calculation method:	See Section 8.7 Uncertainty
Comments:	N/A

Data / Parameter:	$C_{Soil,i,t}$
Data unit:	$tCO_2e\ ha^{-1}$
Description:	Soil Organic Carbon stock within the project boundary in stratum i in year t
Equations	2, 3
Source of data:	Measured according to Section **9.3.4 Soil core approach to estimating soil carbon**
Description of measurement methods and procedures to be applied:	See Section **9.3.4 Soil core approach to estimating soil carbon** and Section 8.2.3
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	BD

Data unit:	g cm^{-3}
Description:	Bulk density, as determined in laboratory (Dry bulk density)
Equations	22
Source of data:	Direct measurements, or from a relationship with organic carbon content provided by the scientific literature.
Description of measurement methods and procedures to be applied:	Mass of soil material after drying per volume of soil material, based on commonly accepted procedures by the scientific community. See Section **9.3.4 Soil core approach to estimating soil carbon**
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$Thickness$
Data unit:	cm
Description:	Thickness of soil horizon based of subdivisions of soil cores
Equations	22
Source of data:	Measured according to section 9.3.4
Description of measurement methods and procedures to be applied:	See section 9.3.4

Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$Ndepth$
Data unit:	Dimensionless
Description:	Number for soil horizons, based on subdivisions of soil cores
Equations	22
Source of data:	Measured according to section 9.3.4
Description of measurement methods and procedures to be applied:	See section 9.3.4
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these

	sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$\%C_{alloch}$
Data unit:	Percentage
Description:	Percentage of the total soil organic carbon that is allochthonous
Equations	3, 4
Source of data:	$\%C_{alloch}$ may be estimated using either: 4. Published values 5. Field-collected data 6. Modelling Needelman et al. (2018) provide a value for the percentage of the total soil organic carbon that is allochthonous ($\%C_{alloch}$) based on the percentage soil carbon, which can be used for mangroves with mineral soils.
Description of measurement methods and procedures to be applied:	See section 9.3.4 and section 8.2.3
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$C_{Soil\_Alloch,i,t}$

Data unit:	$tCO_2e\ ha^{-1}$
Description:	Deduction from the SOC pool to account for the percentage of the carbon stock that is derived from allochthonous soil organic carbon
Equations	2, 3
Source of data:	Calculated based on measured Baseline Soil Organic Carbon stock and percentage of the total soil organic carbon that is allochthonous
Description of measurement methods and procedures to be applied:	See section 9.3.4 and section 8.2.3
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$\%C_{soil}$
Data unit:	Percentage
Description:	Percentage of soil organic C
Equations	4, 6
Source of data:	Direct measurements or may be derived from direct measurements of soil organic matter. These measurements may be made using samples collected in Section 9.3.4 or indirectly from the soil carbon percentage as described in Section 8.2.3.
Description of measurement methods	See section 9.3.4 and section 8.2.3

and procedures to be applied:	
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$\%C_{autoch}$
Data unit:	Percentage
Description:	Percentage of the total soil organic carbon that is allochthonous
Equations	4
Source of data:	Measured through field-collected data
Description of measurement methods and procedures to be applied:	See section 9.3.4 and section 8.2.3
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**

Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$\%OM_{soil}$
Data unit:	Percentage
Description:	Percentage of soil that is organic matter
Equations	5, 6
Source of data:	Direct measurements based on loss-on-ignition or may be derived from direct measurements of soil carbon. These measurements may be made using samples collected in Section 9.3.4 or indirectly from the soil carbon percentage as described in Section 8.2.3.
Description of measurement methods and procedures to be applied:	See section 9.3.4 and section 8.2.3
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$\%OM_{depsed}$
Data unit:	Percentage
Description:	Percentage of deposited sediment that is organic matter

Equations	5, 7
Source of data:	Direct measurements based on loss-on-ignition or may be derived from direct measurements of soil carbon. These measurements may be made using samples collected in Section 9.3.4 or indirectly from the soil carbon percentage as described in Section 8.2.3.
Description of measurement methods and procedures to be applied:	See section 9.3.4 and section 8.2.3
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$\%OM_{autoch}$
Data unit:	Percentage
Description:	Percentage of soil that is autochthonous organic matter
Equations	5
Source of data:	Determined based on the values applied for $\%OM_{soil}$ and $\%OM_{depsed}$
Description of measurement methods and procedures to be applied:	See section 8.2.3
Frequency of monitoring/recording:	At every monitoring period

QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$\%C_{depsed}$
Data unit:	Percentage
Description:	Percentage of deposited sediment that is organic C
Equations	7, 9
Source of data:	May be estimated directly using loss-on-ignition (LOI) data or indirectly from soil carbon percentage as described in Section 8.2.3. These measurements may be made using samples collected on sediment tiles or through collection and carbon analysis (see Section 9.3.4)
Description of measurement methods and procedures to be applied:	See section 8.2.3
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculate the change in Soil Organic Carbon
Calculation method:	See Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**
Comments:	Refer to procedures in Section 8.2.3 and Section **9.3.4 Soil core approach to estimating soil carbon**. For all equations in these

	sections, the subscript BSL must be substituted by PS to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$E_{Soil,CH4,i,t}$
Data unit:	tCO_2e
Description:	CH_4 emissions from the SOC pool in the project scenario in stratum i in year t;
Equations	9
Source of data:	Measured through field measurements. See Section **9.3.5 Monitoring CH4 emissions**
Description of measurement methods and procedures to be applied:	See section 9.3.5
Frequency of monitoring/recording:	At every monitoring period
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculation of project emissions
Calculation method:	See Section 8.3 Project Emissions and Section **9.3.5 Monitoring CH4 emissions**
Comments:	N/A

Data / Parameter:	$E_{CH4-daily,i,t}$
Data unit:	mg CH_4 m^{-2} d^{-1}
Description:	Average daily CH_4 emissions in the baseline scenario based on direct measurements of stratum i in year t
Equations	9
Source of data:	Measured through field measurements. See Section **9.3.5 Monitoring CH4 emissions**

Description of measurement methods and procedures to be applied:	See Section **9.3.5 Monitoring CH4 emissions**
Frequency of monitoring/recording:	At least monthly during the monitoring period.
QA/QC procedures to be applied:	See Section **9.3.6 Uncertainty and quality management**
Purpose of data:	Calculation of project emissions
Calculation method:	See Section 8.3 Project Emissions and Section **9.3.5 Monitoring CH4 emissions**
Comments:	N/A

9.3 Description of the Monitoring Plan

Project proponents must detail the procedures for collecting and reporting all data and parameters listed in Section 9.2. The monitoring plan must contain at least the following information:

- A description of each monitoring task to be undertaken, and the technical requirements therein;
- Definition of the accounting boundary, spatially delineating any differences in the accounting boundaries and/or quantification approaches;
- Data to be collected and data collection techniques and sample designs for directly-sampled parameters;
- Anticipated frequency of monitoring, including anticipated definition of "year";".
- Quality assurance and quality control (QA/QC) procedures to ensure accurate data collection and screen for, and where necessary, correct anomalous values, ensure completeness, perform independent checks on analysis results, and other safeguards as appropriate;
- Data archiving procedures, including procedures for any anticipated updates to electronic file formats. All data collected as a part of monitoring process, including QA/QC data, must be archived electronically and be kept at least for two years after the end of the last project crediting period; and
- Roles, responsibilities and capacity of monitoring team and management.

9.3.1 Monitoring of project implementation

Continued compliance with the applicability conditions of this methodology must be ensured by monitoring that:

- Commercial forestry is not present within the project area
- The burning of organic soil as a project activity does not occur.
- N-fertilizers are not used within the project area in the project scenario.

9.3.2 Stratification and sampling framework

Stratification of the project area into relatively homogeneous units may either increase the measuring precision without increasing the cost unduly or reduce the cost without reducing measuring precision because of the lower variance within each homogeneous unit. The project proponent must present in the project description an ex-ante stratification of the project area or justify the lack of it. The number and boundaries of the strata defined ex ante may change during the project crediting period (ex post).

The ex-post stratification may only be updated where unexpected disturbances occur during the project crediting period (e.g., due to rise of sea level, fire, pests or disease outbreaks), affecting differently various parts of an originally homogeneous stratum.

Established strata may be merged if the reasons for their establishment are no longer relevant.

The sampling framework, including sample size, plot size, plot shape, and determination of plot location must be specified in the project description. Where changes in carbon stocks are to be monitored (e.g., in trees), permanent sampling plots must be used, noting the following:

1. To determine the sample size and allocation among strata, the latest version of the CDM tool AR-Tool03 Calculation of the number of sample plots for measurements within A/R CDM project activities may be used. The targeted confidence interval must be 90% or 95%. Where a 90% confidence interval is adopted and the width of the confidence interval exceeds 20% of the estimated value or where a 95% confidence interval is adopted and the width of the confidence interval exceeds 30% of the estimated value, an appropriate confidence deduction must be applied, as specified in Section **9.3.6 Uncertainty and quality management**.
2. In order to avoid bias, sample plots should be marked inconspicuously.
3. The sample plot size must be established according to common practice in forest, vegetation and soil inventories.

To avoid subjective choice of plot locations, the permanent sample plots must be located either systematically with a random start or completely randomly inside each defined stratum. The geographical position (GPS coordinate), administrative location, stratum and stand, series number of each plot, as well as the procedure used for locating them must be recorded and archived. The sampling plots are to be as evenly distributed as possible, where larger strata have more plots than smaller strata. However, remote areas and areas with poor accessibility may be excluded for the location of sampling plots. Such areas must be mapped as separate strata and for these strata accounting of carbon stocks in tree biomass in the project scenario is conservatively omitted (see Section

4. **9.3.2 Stratification and sampling framework**).

The choice of monitoring frequency must be justified in the project description.

9.3.3 Sampling Aboveground and Belowground Biomass

Projects shall use the CDM methodology tool "*Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities*" section 8 for the estimation of carbon stock in mangrove trees at a point in time. Estimations by measurement of sample plots shall be estimated either through Stratified random sampling or Doubling sampling.

Project Proponents are permitted to utilise emerging technology (e.g. remote sensing) with known uncertainty to measure changes in carbon stocks for the class of vegetation cover. These emerging technology approaches must be supported by peer-reviewed literature which validates their accuracy and uncertainty. Justification for the chosen approach should be documented in the Project Description Document supplemented with appropriate evidence. Any uncertainty in the approach used must be discounted for. All parameters, data sources and assumptions applied by the emerging technology must be documented in the Project Description Document. Data sources should be publicly available to enable the replication of results.

9.3.4 Soil core approach to estimating soil carbon

Soil organic carbon ($C_{Soil,i,t}$) may be estimated by determining the organic carbon accumulated above a consistent reference plane. The reference plane must be established using a marker horizon (most commonly using feldspar)[24], a strongly contrasting soil layer (such as the boundary between organic and mineral soil materials), an installed reference plane (such as the shallow marker in a surface elevation table)[25], a layer identified biogeochemically (such as through radionuclide, heavy metal, or biological tracers)[26], a layer with soil organic carbon indistinguishable from the baseline SOC concentration or other accepted technologies. Note that feldspar marker horizons should not be used in systems where they are unstable, such as some sandy soils and systems with significant bioturbation. The material below the reference plane may be conservatively assumed to have zero change due to project activities.

The material located above the reference plane must be analysed for total carbon and bulk density. Sediment samples may be collected for the estimation of $\%C_{depsed}$ (see Section 8.2.3) using sediment

[24] Cahoon & Turner (1989)

[25] Cahoon et al. (2002)

[26] DeLaune et al. (1978)

tiles,[27] through collection of suspended sediments in tidal channels during a period of high suspended sediment concentration or by collecting cores of sediment deposits in tidal flats. Total organic carbon must be analysed directly using CHN elemental analysis or the Walkley-Black chromic acid wet oxidation method or determined from loss-on-ignition (LOI) data using the following equation[28]:

$$\%C = 0.415 \times \%OM + 2.8857 \quad \text{(Equation 21)}$$

Inorganic carbon should be removed from samples if present in significant quantities, usually through acid treatment (such as sulfurous or hydrochloric acid). Live coarse below-ground tree biomass should be removed from soil samples prior to analysis. Additional live below-ground biomass may be removed or included. Soil samples collected may be aggregated to reduce the variability.

The mass of carbon per unit area is calculated as follows:

$$C_{Soil,i,t} = \sum_{i}^{Ndepth}(CF_{SOC\_sample} \times BD \times Thickness \times 100 \times \frac{44}{12}) \quad \text{(Equation 22)}$$

Where:

$C_{Soil,i,t}$	=	Carbon stock in the project scenario in stratum i in year t; $tCO_2e\ ha^{-1}$
$Ndepth$	=	Number for soil horizons, based on subdivisions of soil cores
CF_{SOC_sample}	=	Carbon fraction of the sample, as determined in laboratory; %
BD	=	Bulk density, as determined in laboratory; $g\ cm^{-3}$
$Thickness$	=	Thickness of soil horizon; cm
100	=	Conversion factor of $g\ cm^{-3}$ to $tonne\ ha^{-1}$
$\frac{44}{12}$	=	Ratio of molecular weight of CO_2 to carbon; dimensionless

All samples must be kept under dark conditions at 4C until retrieved to the lab. All samples must be processed within 6 days post collection.

9.3.5 Monitoring CH_4 emissions

[27] Pasternack & Brush (1998)

[28] Kauffman et al. (2011); Howard et al. (2014)

Direct measurement of CH_4 emissions may be made with either a closed chamber technique or a chamber-less technique such as eddy covariance flux. For eddy covariance methods, the guidelines presented in Appendix 1: Default eddy covariance measurement methods for methane must be followed, taking into account the additional guidance below.

Flux measurements are expected to conform to standard best practices used in the scientific community[29]. The basic design of the closed chamber requires a base that extends into the soil (5 cm minimum), and a chamber that is placed over the plants and sealed to the base. To prevent the measurement from disturbing CH_4 emissions, the base should be placed at least one day in advance, and the plot should be approached on an elevated ramp or boardwalk when taking samples, although failure to do so is conservative because it will cause higher fluxes. CH_4 flux is calculated as the difference in initial and final headspace CH_4 concentration, without removing non-linear increases caused by bubble (ebullition) fluxes that may have occurred. Initial and final concentrations will be determined as the average of duplicate determinations. Because CH_4 emissions can be low from tidal wetlands, it may be necessary to enclose large areas (≥ 0.25 m^2) or lengthen the measurement period to improve sensitivity.

Fluxes must be measured in the stratum with the highest emissions. For CH_4, these are likely to be strata in the wettest strata that support emergent vegetation but may include stagnant pools of water. Eddy flux towers must be placed so that the footprint lies in the stratum with the highest CH_4 emissions for 50% of the time. CH_4 fluxes must be measured when the water table is <10cm cm from the soil surface, during times of year when emissions are highest, such as the warmest month and/or wettest month. When CH_4 emission rates incorporate measurements from periods of time outside the peak, they must be made at approximately monthly intervals.

In addition to the conservative principles above, the project proponent must consider other factors that are specific to the method applied. In particular, closed chambers must be transparent and deployed in daylight unless it can be shown that CH_4 emissions are not sensitive to light.

The analysis of methane from chamber samples must meet or exceed USEPA QA/QC requirements. The selected laboratory must provide written pre-analysis sample processing procedures, specific chemistry test methods and detection limits for the analysis. Sample analyses must follow the EPA Method 3C (Determination of Carbon Dioxide, Methane, Nitrogen, and Oxygen from Stationary Sources). Instrument calibration must comply with EPA Protocol Gaseous Calibration Standards.

Regardless of method, emissions must be averaged and expressed as daily (24 hour) rates and converted to annual estimates using the following equation:

$$E_{Soil,CH4,i,t} = E_{CH4-daily,i,t} \times 365 \times GWP_{CH4} \times 100$$ (Equation 23)

Where:

$E_{Soil,CH4,i,t}$	=	CH_4 emissions from the SOC pool in the project scenario in stratum i in year t; tCO_2e
$E_{CH4-daily,i,t}$	=	Average daily CH_4 emissions in the baseline scenario based on direct measurements of stratum i in year t; mg CH_4 m^{-2} d^{-1}

29 Oremland (1975)

365	=	Conversion of daily value to year
GWP_{CH4}	=	Global Warming Potential of CH_4 (the latest IPCC GWP value for 100-year time horizon must be used).
t	=	1, 2, 3, … t* years elapsed since the project start date; years
i	=	1, 2, 3 …M_{WPS} strata in the project scenario

9.3.6 Uncertainty and quality management

Quality management procedures are required for the management of data and information, including the assessment of uncertainty relevant to the project and baseline scenarios. As far as practical, uncertainties related to the quantification of GHG emission reductions and removals by sinks should be reduced.

To help reduce uncertainties in the accounting of emissions and removals, this methodology uses whenever possible the methods from the GPG-LULUCF, GPG-2000, the IPCC's Revised 2006 Guidelines and peer-reviewed literature. Despite this, potential uncertainties still arise from the choice of parameters to be used. Uncertainties arising from input parameters would result in uncertainties in the estimation of both baseline net GHG emissions and project net GHG emissions, especially when global default factors are used. The project proponent must identify key parameters that would significantly influence the accuracy of estimates. Local values that are specific to the project circumstances must then be obtained for these key parameters, whenever possible. These values should be based on:

- Data from well-referenced peer-reviewed literature or other well-established published sources[30];
- National inventory data or default data from IPCC literature that has, whenever possible and necessary, been checked for consistency against available local data specific to the project circumstances; or
- In the absence of the above sources of information, expert opinion may be used to assist with data selection. Experts will often provide a range of data, as well as a most probable value for the data. The rationale for selecting a particular data value must be described in the project description.

In choosing key parameters, or making important assumptions based on information that is not specific to the project circumstances, such as in use of default data, the project proponent must select values that will lead to an accurate estimation of net GHG emission reductions, taking into account uncertainties.

If uncertainty is significant, the project proponent must choose data such that it indisputably tends to under-estimate, rather than over-estimate, net GHG project benefits.

To ensure that carbon stocks are estimated in a way that is accurate, verifiable, transparent, and consistent across measurement periods, the project proponent must establish and document clear standard operating procedures and procedures for ensuring data quality. At a minimum, these procedures must include:

- Comprehensive documentation of all field measurements carried out in the project area. This document must be detailed enough to allow replication of sampling in the event of staff turnover between monitoring periods.

[30] Typically, citations for sources of data used should include: the report or paper title, publisher, page numbers, publication date, etc. (or a detailed web address). If web-based reports are cited, hardcopies should be included as annexes in the project description if there is any likelihood that such reports may not be permanently available.

- Training procedures for all persons involved in field measurement or data analysis. The scope and date of all training must be documented.
- A protocol for assessing the accuracy of plot measurements using a check cruise and a plan for correcting the inventory if errors are discovered.
- Protocols for assessing data for outliers, transcription errors, and consistency across measurement periods.
- Data sheets must be safely archived for the life of the project. Data stored in electronic formats must be backed up.

9.3.7 Expert Judgement

The use of expert judgment for the selection and interpretation of methods, selection of input data to fill gaps in available data, and selection of data from a range of possible values or uncertainty ranges, is well established in the IPCC 2006 good practice guidance. Obtaining well-informed judgments from domain experts regarding best estimates and uncertainties is an important aspect in various procedures throughout this methodology. The project proponent must use the guidance provided in Chapter 2 (Approaches to Data Collection), in particular, Section 2.2 and Annex 2A.1 of the IPCC 2006 good practice guidance.

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Appendix 1: Default eddy covariance measurement methods for methane

Eddy covariance or eddy correlation is a widely accepted micrometeorological technique to estimate flux of heat, water, atmospheric trace gases and pollutants and relies on turbulence to calculate fluxes. The semi-continuous nature of sampling allows for diurnal, seasonal, and annual budgets of energy and GHGs between the biosphere and atmosphere. Measuring carbon fluxes with the eddy covariance method has the advantage of covering broader space and more continuous measurements, unlike chamber flux techniques. The two methods may be used in concert in a heterogeneous landscape to evaluate flux contribution of distinct landforms (hummocks, hollows, ditches, open water; Baldocchi et al. 2011) to create a more accurate landscape or project area GHG budget.

Standard operating procedures for designing flux studies and data analyses are being unified by global and regional bio-meteorological communities, such as FLUXNET and AMERIFLUX, respectively. The information presented here draws from their basic guidelines for eddy covariance methods. Open source software is increasingly available for computing GHG fluxes that have been validated by a 'Gold Standard' (see AMERIFLUX, http://public.ornl.gov/ameriflux/sop.shtml).

The project proponent must use one of the software packages for eddy covariance data processing listed below, unless they can demonstrate with peer-reviewed evidence that their alternative approach yield the equivalent or more accurate results. An inter-comparison of some of these software packages for eddy covariance data quality control was reviewed by Mauder et al. (2008), and any of these packages must be considered equally acceptable for computing GHG fluxes. Eddy covariance algorithms may be used in other commercial software, such as MatLab, but will require justification from the project proponent.

- EddyPro 4.0 (fully documented, maintained, and supported by LI-COR®, Inc.)
- ECO2S (IMECC-EU)
- EdiRe (Rob Clement, University of Edinburgh)
- TK3 (Matthias Mauder and Thomas Foken, University of Bayreuth)
- ECPack (GNU Public License; Wageningen University);
- EddySoft (Olaf Kolle and Corinna Rebmann, Max-Planck Institute for Biogeochemistry)
- Alteddy (Jan Elbers, Alterra Institute in Wageningen)

Eddy flux is equivalent to the mean dry air density, multiplied by the mean covariance of instantaneous deviations of vertical wind velocity and the mixing ratio of a constituent (methane and carbon dioxide) in air. These covariances are corrected for density fluctuations due to water vapor (Baldocchi et al. 2011).

The eddy covariance technique, while applied in many different ecosystems, is most easily applied in areas where the canopy is relatively homogeneous and the terrain is horizontal. Thus herbaceous wetlands lend themselves well to this technique. Caution is needed when deploying eddy covariance stations, so that vertical disruptions (canopy height changes, trees, buildings) to the boundary layer of interest are minimized. The seven main assumptions for eddy covariance technique are outlined here (from Burba and Anderson 2007) and specific requirements to satisfy these assumptions are described throughout this appendix.

1. Measurements at a point represent an upwind area

2. Measurements are collected in the layer of interest (eg, constant flux layer)
3. The fetch is assumed to be adequate and measures the area of interest
4. Flux is fully turbulent
5. Terrain is horizontal
6. Average of vertical fluctuations is zero, density fluctuations are negligible, and flow convergence and divergence does not occur.
7. Instruments are capable of detecting small changes and measuring at a high frequency (>10 Hz).

There are sources of error that can affect flux computations; however, these errors, such as time lags in measurements and unlevelled instruments, are adjusted according to accepted methods during data processing (see Section 4 of this Appendix)

1. Sampling Requirements

The project proponent must plot a time series of 30 min data including methane concentration, surface friction velocity and temperature. Data points must be omitted based on the following thresholds:

- Methane concentration must not be less than ambient (< 1.7 ppm) or the regional average, which is available from the nearest NOAA ERSL laboratory field station (or equivalent).
- Surface friction velocities less than 0.10 m/s or greater than 1.2 m/s.

The following criteria establish the frequency of measurements within each day:

1) A sample interval is 0.5 hr.

2) A minimum of 12 samples must comprise a daily flux mean.

3) One missing sample between two samples may be linearly interpolated. No interpolation is allowed for time periods greater than 1 hr.

4) A list of interpolated samples must be recorded and provided to the verifier.

A minimum of 3 days must be sampled per calendar month, with no less than 7 days between sampling events.

2. Eddy Covariance Instrumentation

Direct measurements of methane at high frequencies (10-20 Hz) are needed for eddy covariance calculations. For methane, laser absorption spectroscopy is common, and suitable instrumentation is equivalent to those of the closed path Los Gatos tunable diode laser spectrometer (DLT-100 Fast Methane Analyzer), the open path LICOR 7700 (Wave Modulated Spectroscopy), and the Campbell Scientific Trace

Gas Analyzers. The chosen methane analyzer must have a resolution of ≤5 ppb methane at 10 Hz (@ 2000 ppb methane) and measurement frequencies must not be less than 10 Hz.

In addition to methane, other meteorological variables must be measured at a frequency (≥10 Hz) equivalent to the gas measurements, including wind and turbulence (three-dimensional sonic anemometer), water vapor, and air temperature. The chosen water vapor analyzer must have a resolution ≤ 0.005 mmol H20/mol air (@ 10 mmol H20/mol air). The sonic anemometer must have a resolution ≤ 0.01 m/sec (@ standard velocity of 12 m/sec). Water vapor measurements will be used to correct for air density fluctuations.

3. Tower Configuration

2.1 Orientation of Sensors and Equipment

A single tower must be used with the elevated array of eddy covariance instruments contained within a 3 m radius from the center of the tower. If a platform is used, the maximum footprint of the platform and support equipment (solar panels, flow modules, batteries) must not exceed a 5 m radius from the center of the tower base.

High frequency measurements of air properties for eddy covariance require short distances between sensors to minimize time response errors. Instrumentation on the tower must be integrated (ie, trace gas analyzers, anemometer, and temperature sensors) such that distance and orientation between sensors sample the representative air mass properties and allow frequency response corrections.

While configurations may vary depending on the wind direction of interest, the maximum horizontal distance of methane sensor or water vapor intake must not exceed 1.0 m from the center of the anemometer, unless the project proponent provides justification. The distance of the intake sensor for air density and methane sensor must be measured and recorded for elevation, in addition to the northward and eastward separation relative to the center of the sonic anemometer.

2.2 Landscape Location of Tower

For conservative project emissions estimates, a primary requirement is to locate the tower within the strata where the highest emissions are anticipated, and at least one-half of the footprint area (as defined by the 80% mean footprint distance) must include the highest emitting strata. The slope of the site must not exceed 1% (1 m vertical /100 m horizontal distance) in any direction within a 200m radius of the eddy covariance tower. The tower may be positioned in the landscape to capture specified wind direction(s) or it may be centrally placed within a homogeneous habitat with adequate fetch to measure all wind directions. In either case, the terrain must be homogeneous with respect to the mean 80% footprint distance. Homogeneous terrain here is defined as an area that contains no more than 25% areal coverage of patch vegetation that exceeds twice the dominant plant canopy height. A patch is defined as ≥100 m^2 of species (twice the dominant plant canopy height) covering >70% of the 100 m^2.

2.3 Sensor Height

As a general rule a sensor height of 1.0 m above the canopy can integrate fluxes from 100 m upwind under turbulent conditions. Sensor height above the canopy must be no less than one and one-half greater than the dominant plant canopy height in the footprint area. It is permissible to increase or decrease sensor height on the tower to accommodate changes in plant canopy height, as long as the sensor height is maintained above twice the canopy height. Alternately, during data post-processing vegetation canopy height may be adjusted without changing sensor height. Physical changes in sensor height must be recorded and incorporated as offsets during data processing.

2.4 Fetch and Flux Footprint

Fetch is described as the horizontal extent from the tower where flux is sampled, whereas the flux footprint describes how much of the measured flux comes from an area at a given horizontal distance. Sufficient fetch is needed to develop an internal boundary layer where fluxes are constant with height (Baldocchi et al. 2001). For every 1.0 m increase in vertical plant structure above an effective surface, approximately 100 m of fetch is needed to readjust the internal boundary layer (Businger 1986, in Baldocchi et al. 1988). To provide adequate fetch, the effective surface (dominant canopy height of interest) must be provided by the project proponent and the sensor height must be twice the dominant canopy height within a minimum radius of 100 m from the tower. If patch vegetation is present it must not exceed the 25% area threshold identified in Section 2.2.

2.4.1 Footprint Distance Estimation

The mean 80% footprint distance provides the verifier with information to confirm that flux measurements are being collected within an area that is homogeneous. Here, mean 80% footprint distance can be estimated with a predictive model and using daytime turbulence parameters that are typical of the region (ie, from a nearby meteorological station) and the characteristics of the site.

The predicted mean 80% footprint distance must be estimated by the project proponent based on the methodology by Klujn et al. (2004), which uses turbulence parameters to predict the location or distance that influences a percentage of the flux. In this case, the project proponent must provide parameter estimates and the results of the predicted footprint distance with 80% flux contribution (online footprint parameterization, http://footprint.kljun.net/varinput.php) to the verifier, based on data known for the project site or estimates from local meteorological stations for the time period of measurement. The parameter estimates must include:

σW = standard deviation of daytime vertical velocity fluctuations (m/s)
$u*$ = surface friction velocity (m/sec) z
m = measurement height (m)
hm = planetary boundary layer height (m) or 1000 m
zm = roughness length (m) or 1/10th of the average canopy height

2.5 Calibration

Calibration of methane sensors must be performed by the factory or user according to manufacturer guidelines. When LICOR equipment is used, the intervals for checks and calibration are provided here, while detailed calibration/zero instructions can be accessed via the LICOR website. The methane analyzer (LI-7700) must be fully calibrated spanning a 0 and 10 ppm methane concentration standard at least once annually with standard gases (1% accuracy). Zero and 10 ppm checks of the methane analyzer with hydrocarbon-free and 10 ppm standard gases (accuracy for zero gases = <0.1 ppm Total Hydrocarbon Concentration; accuracy for 10 ppm methane = <0.5 ppm methane) must be conducted at a minimum of twice every six months over one year of data collection. The LI-7200, which measures water vapor and carbon dioxide, must be returned to the factory at least once every three years to confirm the stability of coefficient values on the factory drift table.

3. Scale to Project Area

Project field monitoring designs may fall into one of several general approaches that may embrace one uniform habitat type or multiple habitat types in a single location, periodic habitat sampling, or multiple eddy covariance towers contemporaneously measuring different habitats.

1) Stationary single habitat: The simplest case is restricting long-term measurements to a single location that maximizes flux estimates from a homogeneous habitat across seasonal atmospheric and environmental events. The assumption of this approach is that the range of project-scale variability in GHG emissions is adequately characterized over an annual period.
2) Stationary multiple habitats: The eddy covariance tower may be placed a single location that generates information from different habitats that have different source/sink effects. In this case, data are isolated by the wind direction or quadrant that corresponds to the habitat (open water, scrub-shrub, herbaceous).
3) Complete or periodic coverage of multiple habitats: For project areas with diverse habitats, each habitat type is individually instrumented and measuring simultaneously for valid inter-habitat comparisons. Another approach is to make periodic movements to different habitats with an eddy covariance tower. The degree to which periodic deployments in different locations approximate average conditions must be demonstrated by the project proponent.

Regardless of the method chosen above to scale from the tower location to the project area, project proponents must justify that the tower locations selected result in conservative estimates of methane emissions flux. To do this, project proponents must:

1) Stratify the project area based on measureable factors expected to impact methane emissions flux. These factors may include but are not limited to elevation, vegetation cover, and salinity.
2) Calculate the percentage of the total project area that falls into each methane emissions flux stratum.
3) Using the mean 80% footprint distance defined above, calculate the percentage of the expected tower footprint that falls within each stratum.
4) Demonstrate that, if the proportion of the tower footprint area that falls within each stratum differs from the proportion of the total project area that falls within each stratum, the tower footprint area contains a proportionally greater area of strata expected to have high methane emissions flux. For example, if two strata are identified (low and high emissions flux), and the project area is 40% low and 60% high, a tower footprint that includes 70% high emissions flux strata and 30% low is acceptable, while a footprint that includes 55% high emissions flux strata and 45% low is not. If evidence can be presented that a tower footprint is completely homogenous and all strata are sampled separately, this requirement can be considered satisfied.

$$E_{CH4-daily,i,t} = (\overline{\rho a}\,\overline{w's'}) \times 5.61 \times 10^{-3} \times GWP_{CH4} \quad \text{(Equation 23)}$$

Where:

$E_{CH4-daily,i,t}$	=	Average daily CH_4 emissions in the baseline scenario based on direct measurements of stratum i in year t; mg CH_4 m^{-2} d^{-1}
$\overline{\rho a}$	=	mean air density for a 0.5 hour sample interval in stratum i in year t; µmol air/m^3
$\overline{w's'}$	=	mean covariance of instantaneous vertical wind velocity and mixing ratio of CH_4 in air in stratum i in year t
w'	=	instantaneous vertical wind velocity in stratum i in year t; m/sec
s'	=	instantaneous mixing ratio of CH_4 in air in stratum i in year t; µmol gas/µmol air
5.61×10^{-3}	=	unit conversion of µmol CH_4/m^2 /s to tCH_4/ac/day
GWP_{CH4}	=	Global Warming Potential of CH_4 (the latest IPCC GWP value for 100-year time horizon must be used).

4. Data Processing and Analyses

Decades of eddy covariance methodology research has resulted in some widely accepted sequences of processing steps and corrections that should be applied. As an evolving science, however, there are debatable topics under discussion. The traditional steps in eddy covariance data processing are outlined below and the project proponent is responsible for specifying how data processing conforms to accepted methods (adapted from Burba and Anderson, 2007).

Step	Accepted methods	References
1. Raw Data unit conversion	Raw voltage to unit conversion	
2. Despike	Signals greater than 6 times the standard deviation for a given averaging period (30 min) must be removed for vertical wind velocity and gas concentration	
3. Calibration coefficients	• may be done during data post processing; or, • user input corrections embedded in the instrument software and metadata	
4. Co-ordinate rotation	• rotation to mean vertical velocity is equal to zero over a 30 min sample interval; or, • planar fit method; or, • sonic tilt correction algorithms	

5. Detrending	• 30 min block averaging must be used • linear and non-linear de-trending should be justified by project proponent	
6. Frequency response corrections	Corrections may include: sensor separation, scalar path averaging, high-low pass filtering.	Moore, C.J. 1986. Frequency response corrections for eddy correlation systems. Boundary Layer Meteorology, 37:17-35.
7. Density fluctuation	WPL correction applied to uncorrected covariances or final fluxes.	Webb, E.K., Pearman, G., and Leuning, R. 1980. Correction of flux measurements for density effects due to heat and water vapor transfer. Quarterly Journal of the Royal Meteorological Society, 106:85-100.

The Project Description Document and subsequent Monitoring reports must include a description of the processing software used, assumptions, and data quality control measures, which must include the selected method of coordinate rotation, detrending, and density fluctuation correction.

5. Flux footprint calculations

Flux footprint calculations must employ one of the following methods: Klujn et al. 2004 or Kormann and Meixner 2001. With either method, the project proponent must provide a summary table describing the measured meteorological conditions and the mean 80% footprint distance for the monitoring period. See Equation 23.

Appendix 2: Calculating the Long Term Net Carbon Benefit

Sea level rise is a major potential climate change threat to mangrove ecosystems; mangroves are sensitive to changes in inundation duration and frequency as well as salinity levels that exceed a species-specific physiological threshold of tolerance[31]. Increases in flooding duration can lead to plant death at the seaward mangrove margins as well as shifts in species composition[32], ultimately leading to a reduction in productivity and ecosystem services. Whilst some studies indicate that mature mangroves appear to be resilient to sea level rise, this methodology conservatively assumes that the carbon stocks from aboveground biomass are lost to oxidation following submergence with the carbon being immediately and entirely returned to the atmosphere.

Project proponents must quantify the long term carbon benefits of their project over a 100 year period, where it is expected that sea level rise will result in the loss of mangrove aboveground biomass planted within the project area within the eligible 100 year duration. This long term carbon net benefit quantifies both the enhancements in the carbon stocks within a project area and losses due to sea level rise. For more details on how to calculate the long term net carbon benefit of the project, please see the SOCIALCARBON Guidance document related to this topic.

[31] Ball (1988); Friess et al. (2012)

[32] He et al. (2007); Gilman et al. (2008); Castañeda-Moya et al. (2013)