SOCIALCARBON®

SCM0005 – Methodology for Regenerative Land Management

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Methodology Details

1. Sources

This methodology uses the following sources:

- SOCIALCARBON Standard v6.0
- SOCIALCARBON Standard Definitions
- VM0042 - Methodology for improved agricultural land management v2.0

2. Summary description of the Methodology

This methodology provides procedures to estimate the greenhouse gas (GHG) emission removals resulting from the adoption of regenerative land management practices that increase soil organic carbon (SOC) storage.

The baseline scenario assumes the continuation of pre-project land management practices. Each sample unit's practices within the project area (e.g., each field) applied in the baseline scenario is determined by applying a 3-year historical review period to produce an annual schedule of activities for each sample unit within the project area to determine the baseline scenario practices.

Emission removals are calculated either through a modelled or measured approach. Modelling can be conducted either through the procedures outlined in this methodology, or through SOCIALCARBON Approved Service Providers specialised in Soil Organic Carbon modelling that have their own unique methodology to model carbon removals.

Additionality is demonstrated by the adoption of one or more of the eligible regenerative land management practices eligible under this methodology at the project start date. This methodology is focused on permanent carbon removals and not emission reductions.

A practice change constitutes the adoption, cessation, or some combination thereof, of at least one new practice outlined in the categories included in the eligibility criteria of this methodology. A cessation of at least one pre-existing practice, for example tillage, must exceed 5% of the pre-existing value to demonstrate additionality.

All projects must monitor Soil Organic Carbon within the project area, even if the primary project activity is the reduced application of nitrogen fertilizers[1].

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[1] Li, C., Aluko, O. O., Yuan, G., Li, J., & Liu, H. (2022). The responses of soil organic carbon and total nitrogen to chemical nitrogen fertilizers reduction base on a meta-analysis. *Scientific Reports*, *12*(1), 16326. This meta study found that reduced application of nitrogen fertilizers can result in a short-term decline in Soil Organic Carbon.

Table 1: Additionality and crediting method

Additionality and Crediting Method	
Additionality	Project Method
Crediting Baseline	Project Method

The methodology provides three approaches to quantifying emission removals resulting from the adoption of regenerative land management practices:

- **Quantification Approach 1:** Measure and Model – an acceptable model is used to estimate GHG flux based on edaphic characteristics and actual agricultural practices implemented, using measured initial SOC stocks and climatic conditions in sample fields.
- **Quantification Approach 2:** Measure and Re-measure – direct measurement is used to quantify changes in SOC stocks.
- **Quantification Approach 3:** Modelled – an acceptable model is used to estimate GHG flux based on actual land management practices implemented using published regional SOC stocks and climatic conditions in sample units.

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:

Annual
A plant species that within one year completes its life cycle, reproduces, and dies.

Historical look-back period
The time period prior to the project start date covering at minimum three years and one complete crop rotation. The historical look-back period is used to produce the schedule of activities.

N-fixing species
Any plant species that associates with nitrogen-fixing microbes found within nodules formed on the roots, including but not limited to soybeans, alfalfa, and peas.

Organic nitrogen fertilizer
Any organic material containing nitrogen, including but not limited to animal manure or compost and sewage sludge.

Perennial
A plant species whose life cycle, reproduction and death extends across multiple years.

Professional agronomist
An individual with specialized knowledge, skills, education, experience or training in crop and/or soil science. Such individuals may be agricultural experts like soil scientists, husbandry specialists, agronomists or representatives of a governmental agricultural body.

Project Domain
Set of conditions (including crop type, soil texture and climate) within which model application has been validated.

Sample Point
Sample location of undefined area.

Sample unit
Defined area within the project for which emissions reductions and removals are estimated using the selected quantification approach. The entire project area is divided into multiple sample units that must be demonstrated to be homogenous for the purposes of estimating emission reductions and removals (ERRs) (i.e., similar management activities, soil type, climate etc.). Estimates of ERRs for each sample unit within the project area are then aggregated to produce an estimate for the entire project area. Sample units must be clearly defined in the description of the sampling design provided in the project description document.

Schedule of Activities

Annual schedule of historical management/activity practices applied in the baseline scenario over the historical look-back period (e.g., tillage, planting, harvest, and fertilization events). These practices are based on data requirements repeated over the baseline period and apply to relevant model input variables and parameters.

Regenerative agricultural land management practice
An agricultural practice yielding increased soil organic carbon storage or other climate benefits.

Synthetic nitrogen fertilizer

Any fertilizer made by chemical synthesis (solid, liquid, gaseous) containing nitrogen (N). This may be a single nutrient fertilizer product (only including N), or any other synthetic fertilizer containing N, such as multi-nutrient fertilizers (e.g., N–P–K fertilizers) and ‘enhanced efficiency’ N fertilizers (e.g., slow release, controlled release and stabilized N fertilizers).

Woody perennials

Trees and shrubs having a life cycle lasting more than two years, not including cultivated annual species with lignified tissues, such as cotton or hemp.

Year

A time period t equal to the portion of the monitoring period contained within a single calendar year. This may be less than 365 days.

4. Applicability Conditions

This methodology is applicable under the following conditions:

1. Projects must introduce or implement one or more new changes to pre-existing agricultural management practices which:
    - Reduce tillage/improve residue management;
    - Improve crop planting and harvesting (e.g., agroforestry, crop rotations, cover crops);
    - Improve grazing practices; and/or
    - Utilise integrated pest management using biological controls.

    A change constitutes adoption of a new practice (e.g., adoption of one of the outlined improved land management practices listed in Appendix 1: non-exclusive list of potential improved regenerative land management practices), cessation of a pre-existing practice (e.g., stop tillage or irrigation) or adjustment to a pre-existing practice that is expected to reduce GHG emissions and/or increase GHG removals. Any quantitative adjustment (e.g. reduced application of synthetic fertilizer) must exceed 5% of the pre-existing value, which should be calculated as the average value over the historical look-back period developed for the baseline schedule of activities (see Section 6. Baseline Scenario).

2. Project activities must be implemented on land that is either cropland or grassland at the project start date and remains the same land use throughout the project crediting period. Land use change, for example the conversion from cropland to grassland, may be allowed under the following scenario:
    - Introduction of temporary grassland into cropland is allowed where it can be credibly demonstrated prior to project validation that the integration of perennial crops (e.g., grasses, legumes) into annual crops is planned as part of a long-term agricultural management system (i.e. integrated crop-livestock system). In this case, project proponents must provide documentation of the long-term management plans, covering the duration of the project, that describe proposed practices, crops and expected benefits and outcomes of integrated grassland-cropland management; or
    - Conversion from grassland to cropland or vice versa where it can be credibly demonstrated prior to project validation that project lands in the baseline scenario are degraded and the introduction of improved practices involving land use change would lead to significant improvements in soil health and associated socioenvironmental benefits. In this case, projects must provide documentation demonstrating that lands are degraded at the start of the project and degradation will continue in the

baseline scenario due to the presence of degradation drivers or pressures in the baseline scenario. See Appendix 2: Procedure to demonstrate degradation of project lands in the baseline scenario.

3. The project area land is degraded and will continue to be degraded or continue to degrade.

4. The project area must not have been cleared of native ecosystems within the 20-year period prior to the project start date.

5. The project activity is not expected to result in a sustained reduction of greater than 5% in productivity, as demonstrated by peer-reviewed and/or published studies on the activity in the region or a comparable region, and later assessed through the calculation of leakage.

6. The project activity cannot occur on a wetland.

Additional conditions where models are applied.

The methodology does not mandate the use of any specific model. Provided models are empirical or process-based and supported by sufficient evidence of accuracy and reliability, they may be eligible for use under this methodology.

To be eligible models must be:

a) Publicly available, though not necessarily free of charge, from a reputable and recognized source (e.g., the model developer's website, IPCC or government agency). Sufficient conceptual documentation of inputs, outputs and information on how the model functionally represents SOC dynamics must be accessible to the public. Providing the source code or an API for independent replication of calculations is not required.

b) Shown in peer-reviewed scientific studies to successfully simulate changes in soil organic carbon and trace gas emissions resulting from changes in agricultural management included in the project description;

c) Able to support repetition of the project model simulations. This includes clear versioning of the model use in the project, stable software support of that version, as well as fully reported sources and values for all parameters used with the project version of the model. Where multiple sets of parameter values are used in the project, full reporting includes clearly identifying the sources of varying parameter sets as well as how they were applied to estimate stock change/emissions in the project. Acceptable sources include peer-reviewed literature and statements from appropriate expert groups (i.e., that can demonstrate evidence of expertise with the model via authorship on peer-reviewed model publications or authorship of reports for entities supporting climate smart agriculture, such as FAO or a comparable organisation), and must describe the data sets and statistical processes used to set parameter values (i.e., the parameterization or calibration procedure).

d) The same model version and parameters/parameter sets must be used in both the baseline and project scenarios. Model input data must be derived following guidance in Table 5 (Section 8.2). Model uncertainty must be quantified following guidance in Section 8.5. Models may be recalibrated or revised based on new data, or a new model may be applied, provided the above requirements are met.

e) Validated per datasets and procedures detailed in Section 5.2 of the latest version of SCD0001 or the latest version of VCS' VMD0053 Model Calibration and Validation Guidance for the Methodology for Improved Agricultural Land Management. Model prediction error must be calculated using datasets as described in Section 5.2.5 of SCD0001 or VMD0053 and must use the same parameters or sets of parameters applied to estimate stock change/emissions in the project.

If the model is proprietary to a service provider or project developer, the following conditions must be met in addition to points (b), (c) and (d) above.

f) If proprietary to a service provider, the model's applicability must be approved under the SOCIALCARBON Standard. See Appendix 4: SOCIALCARBON Approved Service Providers for more details on the process for Approved Service Providers; or

g) Been validated for use under the VCS programme for Improved Agricultural Land Management by an VCS Approved VVB.

Note: both the IME assessment report and VVB approval report must be provided to the VVB for evidence.

5. Project Boundary

The spatial extent of the project boundary encompasses all lands subject to implementation of the proposed improved agricultural land management practice(s).

Selected carbon pools included in the project boundary in the baseline and project scenarios are listed in Table 2 below.

Table 2: Selected Carbon Pools under Baseline and Project Activity

Carbon Pools	Included?	Explanation
Aboveground woody biomass	Optional	Aboveground woody biomass must be included where project activities may significantly reduce the pool compared to the baseline. In all other cases aboveground woody biomass is an optional pool. The increase in above ground biomass of annual crops is not considered since in the IPCC accounting system, annual crops are ignored. Where included it is calculated using the *CDM A/R Tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* and *Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.*
Aboveground non-woody biomass	No	Carbon pool is not included because it is not subject to significant changes, or potential changes are transient in nature.

Belowground woody biomass	Optional	This is an optional pool. The increase in below ground woody biomass of annual crops is not considered since in the IPCC accounting system, annual crops are ignored. Where included it is calculated using the *CDM A/R Tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* and *Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.*
Belowground non-woody biomass	No	Carbon pool is not included because it is not subject to significant changes, or potential changes are transient in nature.
Deadwood	No	Carbon pool is not included because it is not subject to significant changes, or potential changes are transient in nature.
Litter	No	Carbon pool is not included because it is not subject to significant changes, or potential changes are transient in nature.
Soil Organic Carbon (SOC)	Yes	A major carbon pool covered by the RLM (Regenerative Land Management) practices.
Wood Products	No	None of the applicable RLM practices decrease the amount of wood products. It has been conservatively excluded.

All projects must monitor Soil Organic Carbon within the project area, even if the primary project activity is the reduced application of nitrogen fertilizers[2].

Table 3: GHG Sources included in or excluded from the Project Boundary

Source		Gas	Included?	Explanation
Baseline & Project Emission sources	Manure deposition	CO_2	No	Not applicable
		CH_4	Yes (scenario based)	Must be included where the project activity is expected to increase livestock by at least 5% compared to the baseline scenario.
		N_2O	Yes (scenario based)	Must be included where the project activity is expected to increase livestock by at least 5% compared to the baseline scenario.
		CO_2	No	Not applicable

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[2] Li, C., Aluko, O. O., Yuan, G., Li, J., & Liu, H. (2022). The responses of soil organic carbon and total nitrogen to chemical nitrogen fertilizers reduction base on a meta-analysis. *Scientific Reports*, *12*(1), 16326. This meta study found that reduced application of nitrogen fertilizers can result in a short-term decline in Soil Organic Carbon.

	Nitrogen fertilizers	CH_4	No	Not applicable
		N_2O	Yes (scenario based)	If in the baseline scenario the project area would have been subject to nitrogen fertilization, or if nitrogen fertilization is greater in the project scenario relative to the baseline scenario, N2O emissions from nitrogen fertilizers must be included in the project boundary.
	Use of N-fixing species	CO_2	No	Not applicable
		CH_4	No	Not applicable
		N_2O	Yes (scenario based)	If nitrogen fixing species are planted in the project, N2O emissions from nitrogen fixing species must be included in the project boundary.
	Burning of biomass	CO_2	No	Carbon stock decreases due to burning are accounted as a carbon stock change.
		CH_4	Yes (scenario based)	Must be included where the project activity is expected to increase this by at least 5% compared to the baseline scenario.
		N_2O	Yes (scenario based)	Must be included where the project activity is expected to increase this by at least 5% compared to the baseline scenario.
	Burning of fossil fuels	CO_2	Yes (scenario based)	Must be included where the project activity is expected to increase this by at least 5% compared to the baseline scenario.
		CH_4	No	Not applicable
		N_2O	No	Not applicable
	Enteric fermentation	CO_2	No	Not applicable
		CH_4	Yes (scenario based)	Must be included where the project activity is expected to increase livestock by at least 5% compared to the baseline scenario.
		N_2O	No	Not applicable

6. Baseline Scenario

Continuation of pre-project land management practices is the most plausible baseline scenario. For each sample unit (e.g., for each field), practices applied in the baseline scenario are determined applying a historic assessment period to produce an annual schedule of activities to be repeated over the first baseline crediting period. Baseline SOC stock change is directly measured or modeled subject to the annual schedule of activities.

Development of schedule of activities in the baseline scenario

For each sample unit, a schedule of activities in the baseline scenario will be determined by assessment of practices implemented during the period prior to the project start date. The interval over which practices are assessed, must be a minimum of 3 years and include at least one complete crop rotation, where applicable.

For each year, information on land management practices must be determined, per the requirements presented in Table 4 below. Guidance on sourcing qualitative and quantitative information is provided in Box 1.

Table 4: Minimum specifications on land management practices for the baseline scenario

Land Management Practice	Qualitative	Quantitative
Crop planting and harvesting	Crop Type(s)	• Approximate date(s) planted (where applicable) • Approximate date(s) harvested / terminated (where applicable) • Crop yield (where applicable)
Nitrogen fertilizer application	• Manure (Y/N) • Compost (Y/N) • Synthetic Nitrogen fertilizer (Y/N)	• Manure type application rate (where applicable) • Compost type application rate (where applicable) • N application rate in synthetic fertilizer (where applicable)
Tillage and/or residue management	• Tillage: (Y/N) • Crop residue removal	• Depth of tillage (where applicable) • Frequency of tillage (where applicable) • Percent of soil area disturbed (where applicable) • Percent of crop residue removed (where applicable)
Grazing practices	• Grazing (Y/N) • Animal type (if applicable)	• Animal stocking rate, i.e., number of animals and length of time grazing in a given area annually (where applicable) • Frequency of harvest

In most cases, quantitative information is associated with related qualitative information (see Box 1). Thus, a negative response on a qualitative element would mean there is no quantitative information related to that practice, whereas a positive response on a qualitative element would then require quantitative information related to that practice.

The schedule of activities in the baseline scenario will be valid until re-evaluation is required by the latest version of the SOCIALCARBON Standard. At the end of each baseline crediting period, production of the commercial crop(s) in the baseline scenario will be re-evaluated. Published regional (subnational) agricultural production data from within the 5-year period preceding the end of the current baseline period must be consulted.

- Where there is evidence of continued production of the relevant commercial crop(s) using the same management practices, the baseline scenario will be valid, continuing with the previous schedule of activities.
- Where there is no evidence of continued production of the relevant commercial crop(s), a new schedule of land management activities (evaluated against common practices in the region) will be developed on the basis based on written recommendations for the sample field provided by an independent professional agronomist or government agricultural extension agent. Recommendations must provide sufficient detail to produce the minimum specifications on agricultural management practices for the baseline scenario as enumerated in Table 4 above.

- Where more than one value is documented in recommendations (e.g., where a range of application rates are prescribed in written recommendations), the principle of conservatism must be applied, selecting the value that results in the lowest expected emissions (or highest rate of stock change) in the baseline scenario.
- Where the evidence is not field-specific, conservatively derived field-specific values must be supported by a documented method of field-specific values justifying the appropriateness of selection.

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

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. This includes demonstrating that the adoption of the suite of proposed project activities is not common practice. Under this methodology, common practice is defined as greater than 20% adoption. To demonstrate that a project activity, or suite of activities, is not common practice, the project proponent must show that the weighted average adoption rate of the predominant proposed project activities within the project spatial boundary is below 20%.

Projects that adopt a single agricultural management practice must demonstrate that their existing activity adoption rate is less than 20% in the region[3]. Where projects utilize more than one agricultural management practice, the project must include a proportionally higher ratio of other activities with lower adoption rates (e.g. cover crops in addition to non-tillage and agroforestry) to bring the weighted average of proposed project activities below 20%.

Evidence must be provided for the adoption rates of each project activity. This evidence must be provided in the form of publicly available information contained in:

1. Agricultural census or other government e.g. survey data;

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[3] Under this methodology, the region can either be the state / country that the project is located or the host country. If the project has activities in more than one country, the mean average adoption rate for the project activity across the host countries must be calculated and used.

2. Peer-reviewed scientific literature;
3. Independent research data; or
4. Reports or assessment compiled by industry associations

To calculate the weighted average adoption rate in each region covered by the project area Equation 1 must be applied:

$$AR = (EA_{a1} \times PA_{a1}) + (EA_{a2} \times PA_{a2}) + \cdots + (EA_{an} \times PA_{an}) \qquad \text{(Equation 1)}$$

$$PA_{a1} = \frac{Area_{a1}}{(Area_{a1} + Area_{a2} + \cdots + Area_{an})}$$

$$PA_{a2} = \frac{Area_{a2}}{(Area_{a1} + Area_{a2} + \cdots + Area_{an})}$$

$$PA_{an} = \frac{Area_{an}}{(Area_{a1} + Area_{a2} + \cdots + Area_{an})}$$

Where:

AR = weighted average adoption rate in region; %

$\mathrm{EA_{a1}}$ = existing adoption rate of largest (i.e., size of land area) most common proposed project activity in region; %

$\mathrm{EA_{a2}}$ = existing adoption rate of second largest most common proposed project activity in region; %

$\mathrm{EA_{an}}$ = existing adoption rate of the n largest most common proposed project activity in region; %

$\mathrm{PA_{a1}}$ = ratio of proposed project-level adoption of Activity $a1$ relative to proposed project-level adoption of Activity $\mathrm{a1}$ + Activity $\mathrm{a2}$ + … + Activity an in region; unitless

$\mathrm{PA_{a2}}$ = ratio of proposed project-level adoption of Activity $a2$ relative to proposed project-level adoption of Activity $\mathrm{a1}$ + Activity $\mathrm{a2}$ + … + Activity an in region; unitless

$\mathrm{PA_{an}}$ = ratio of proposed project-level adoption of Activity an relative to proposed project-level adoption of Activity $\mathrm{a1}$ + Activity $\mathrm{a2}$ + … + Activity an in region; unitless

$\mathrm{Area_{a1}}$ = area of proposed project-level adoption of Activity $a1$ in region; hectares or acres

$\mathrm{Area_{a2}}$ = area of proposed project-level adoption of Activity $a2$ in region; hectares or acres

$\mathrm{Area_{an}}$ = area of proposed project-level adoption of Activity an in region; hectares or acres

n = project activity category

A project proponent may include areas where more than one project activity will be implemented on the same land (e.g., reduced tillage plus agroforestry). Evidence on existing adoption rates for the combined (two or more) activities should be used to calculate the weighted average adoption rate of the proposed combined activities. Where evidence on existing adoption rates for the combined activities is not available, the project proponent may multiply the existing adoption rates (i.e., pre-project) of the individual activities to estimate the combined activity adoption rate. For example, with a statewide existing adoption rate of 40% for reduced-tillage and 10% for agroforestry, the existing adoption rate to be applied (in the weighted average calculation above) for lands combining (stacking) these two activities would be 4% (i.e., 40% x 10%).

8. Quantification of GHG Emission Reductions and Removals

This methodology provides a flexible approach to quantifying emission removals / reductions resulting from the adoption of regenerative land management practices in the project compared to the baseline scenario. This methodology is focused primarily on emission removals through the increase in SOC Stocks within the project area following the implementation of regenerative land management practices, however projects are also permitted to quantify the emission reductions achieved through the reduced / optimized application of nitrogen fertilizers. Any reductions in emissions in the project area compared to the baseline scenario (i.e. reduction in fossil fuel usage) other than from nitrogen fertilizers will be deemed zero. If emissions from the project activities increase (e.g. increased fertilizer usage), the total net increase in emissions must be deducted from the emission removals from SOC stock changes.

Three quantification approaches are available for measuring SOC stock changes:

Quantification Approach 1: Measure and Model. An acceptable model is used to estimate GHG flux based on actual agricultural practices implemented, measured initial SOC stocks, and climatic conditions in sample units.

Quantification Approach 2: Measure and Remeasure. Relevant where models are unavailable or have not yet been validated or parameterized. Baseline carbon stocks are measured in each sample unit and then re-measured prior to each verification period.

Quantification Approach 3: Modelled. An acceptable model is used to estimate GHG flux based on actual land management practices implemented, published regional SOC stocks, and climatic conditions in sample units.

8.1 Baseline Emissions and Removals

Quantification Approach 1 and 3

The baseline is modelled for each sample unit. The model serves to forecast stock change resulting from the schedule of agricultural management activities taking place in the baseline scenario (derived above). Further guidance on biophysical model inputs is elaborated in Table 5.

Table 5: Guidance on collection of biophysical model inputs for the baseline scenario, where required by the model selected

Model Input Category	Timing	Approach
Soil organic carbon stock content and bulk density to calculate SOC stocks (initial)	Determined prior to project intervention via direct measurements at t = 0 or (back-) modelled to t = 0 from measurements collected within ±5 years of t = 0	Published regional-specific data from a reputable source; or Directly measured via conventional analytical laboratory methods, e.g., dry combustion, at t=0 or (back-) modelled to t =0 from measurements collected within +/-5 years of t =0; or determined for t=0 via emerging technologies (e.g., remote sensing) with known uncertainty following the criteria in Appendix 3: guidance on potential emerging technologies to measure SOC stocks and Appendix 5: Considerations for Approaching Uncertainty in Remote Sensing Measurements; or through a SOCIALCARBON Approved Service Provider for this methodology. If the Approved Service Provider has developed a method of quantify SOC change that does not require re-measurement within +/-5 years of t =0, then the project proponent does not need to re-measure. Irrespective of the method applied, and provided the project is not using a SOCIALCARBON approved service provider and the project is using the Quantification Approach 1, the project proponent must collect direct SOC measurements when re-assessing their baseline scenario at the end of each project crediting period.
Soil properties (other than bulk density and soil organic carbon)	Determined ex ante	Directly measured or determined from published soil maps, with known uncertainty. Estimates from direct measurements must satisfy the following: • Derived from representative (unbiased) sampling • Accuracy of measurements is ensured through adherence to best practices.
Climate variables (e.g.,	Continuously monitored ex ante	Measured for each model-specific meteorological input variable at its required temporal frequency (e.g., daily) model prediction interval. Measurements are taken at the closest continuously monitored weather station, not

precipitation, temperature)		exceeding 50 km of the sample field, or from a synthetic weather station (e.g., PRISM[4]).

Quantification Approach 2

The baseline may be measured for each sample unit. For quantitative thresholds listed in Table 4, estimates must be derived from un-biased, representative sampling of the sample site, and accuracy ensured through adherence to best practices.

8.1.1 Soil Organic Carbon Stocks

Quantification Approach 1 & 2

To ensure that changes in SOC stocks do not solely arise from a temporal change in bulk density, SOC stock changes should be calculated on an equivalent soil mass (ESM) basis or soil digital mapping and Remote Sensing ML models. Procedures to calculate SOC stock changes on an ESM basis should be based on (Ellert and Bettany, 1995; Wendt and Hauser, 2013; von Haden, Yang and DeLucia, 2020).

The SOC mass of each depth layer or increment per unit area is calculated as the product of soil mass and OC concentration, where soil mass is the division of the dry sample mass in each depth layer by the area sampled by the probe or auger (Wendt and Hauser, 2013):

$$M_{n,dl,SOC} = \left(\frac{M_{n,dl,sample}}{\pi\left(\frac{D}{2}\right)^2 \times N} \times 10{,}000 \right) \times OC_{n,dl} \qquad \text{(Equation 2)}$$

Where:

$M_{n,dl,SOC}$ = SOC mass in one soil sample depth layer; g

$M_{n,dl,sample}$ = Dry soil sample mass; g

$\pi\left(\frac{D}{2}\right)^2$ = Cross-sectional area of probe or auger with inside diameter D; mm

N = Number of cores sampled

$OC_{n,dl}$ = Organic carbon concentration in each sample; g/kg

The cumulative SOC mass per unit area is then calculated by addition of all sampled depth increments, at least down to 30cm depth. Baseline SOC stocks must be reported for each stratum within the project area, whenever stratification is applied as a sampling strategy (see section 9.3.1). See Appendix 6: General Requirements for Soil Sampling.

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[4] https://climatedataguide.ucar.edu/climate-data/prism-high-resolution-spatial-climate-data-united-states-maxmintemp-dewpoint

Quantification approach 3

The baseline carbon stocks can be based on regional data published by government bodies or peer-reviewed papers. If no regional data is available, the baseline carbon stocks can modelled as per the equation below.

$$SOC_{bsl,i,y} = f\left(SOC_{bsl,i,y-1}\right) \quad \text{(Equation 3)}$$

Where:

$SOC_{bsl,i,y}$ = Estimated Carbon stocks in the soil organic carbon pool in the baseline scenario for sample unit i at the end of period y; tCO2e/unit area

$f\left(SOC_{bsl,i,y-1}\right)$ = Modelled soil organic carbon stocks in the baseline scenario for sample unit i at the end of period $y-1$; tCO2e/unit area

i = Sample unit

8.1.2 Change in Carbon Stocks in Aboveground and Belowground Woody Biomass

If carbon stocks in aboveground and belowground woody biomass are included in the project boundary per Table 3, change in carbon stocks in trees ($\Delta C_{TREE,bsl,i,y}$) and shrubs ($\Delta C_{SHRUB,bsl,i,y}$) in the baseline for sample unit i in year y are calculated using the *CDM A/R Tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities and Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.*

Project Proponents are permitted to utilise emerging technology (e.g. remote sensing) with known uncertainty to measure carbon stocks in woody biomass. If this approach is taken, woody biomass must be measured both in the baseline and project scenario for the length of the project period using this method. 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.

8.1.3 Carbon Dioxide Emissions from Fossil Fuel Combustion

If carbon dioxide emissions from fossil fuel are included in the project boundary per Table 3, they are quantified in the baseline scenario using the following equations:

$$CO2ff_{bsl,i,y} = \frac{\left(\sum_{j=1}^{J} EFF_{bsl,j,i,y}\right)}{A_i} \quad \text{(Equation 4)}$$

Where:

$\mathrm{CO2ff}_{\mathrm{bsl,i,y}}$ = Baseline carbon dioxide emissions from fossil fuel combustion for sample unit i in year y; tCO2e/unit area

$EFF_{\mathrm{bsl,j,i,y}}$ = Carbon dioxide emissions from fossil fuel combustion in the baseline scenario in fossil fuel vehicle/equipment type *j* for sample unit i at the end of period y

$\mathrm{A_i}$ = Area of sample unit i; unit area

j = Type of fossil fuel (gasoline or diesel)

i = Sample unit

$$EFF_{\mathrm{bsl,j,i,y}} = \mathrm{FFC_{bsl,j,y}} \times \mathrm{EF_{CO2,j}} \qquad \text{(Equation 5)}$$

Where:

$FFC_{bsl,j,y}$ = Consumption of fossil fuel type *j* for sample unit i in year y; litres

$EF_{CO2,j}$ = Emission factor for the type of fossil fuel *j* combusted; tCO2e/litre

8.1.4 Methane Emissions from Livestock Enteric Fermentation

If methane emissions from livestock enteric fermentation are included per Table 3 the following equation must be used:

$$CH4ent_{\mathrm{bsl,i,y}} = \frac{\frac{GWP_{CH4} \times \sum_{l=1}^{L} P_{bsl,l,i,y} \times Days_{bsl,l,i,y} \times EF_{ent,l}}{1000 \times 365}}{A_i} \qquad \text{(Equation 6)}$$

Where:

$CH4ent_{\mathrm{bsl,i,y}}$ = Methane emissions from livestock enteric fermentation in the baseline scenario for sample unit i in year y; tCO2e/unit area

GWP_{CH4} = Global Warming Potential for CH4

$P_{bsl,l,i,y}$ = Population of grazing livestock in the baseline scenario of type l in sample unit i in year y; head

$Days_{bsl,l,i,y}$ = Average grazing days per head in the baseline scenario of type l in sample unit i in year y; days

$EF_{ent,l}$ = Enteric emission factor for livestock type l; kg CH4/(head * year)

l = Type of livestock

365 = Days per year

1000 = Kg per tonne

8.15 Methane Emissions from Manure Deposition

If methane emissions from manure deposition are included per Table 3 the following equations must be used:

$$CH4_{md_{\mathrm{bsl,i,y}}} = \left(\frac{GWP_{CH4} \times \sum_{l=1}^{L} (P_{bsl,l,i,y} \times VS_{l,i,y} \times Days_{bsl,l,i,y} \times EF_{CH4,md,l}}{10^6 \times A_i}\right) \quad \text{(Equation 7)}$$

Where:

$CH4_{md_{\mathrm{bsl,i,y}}}$ = Baseline CH4 emissions from manure deposition in the baseline scenario for sample unit i in year y; tCO2e/unit area

$EF_{CH4,md,l}$ = Emission factor for methane emissions from manure deposition for livestock type l; g CH4/kg volatile solids

$VS_{l,i,y}$ = Average volatile solids excretion per head for livestock type l in sample unit i in year y; kg volatile solids / (head * day)

$Days_{bsl,l,i,y}$ = Average grazing days per head in the baseline scenario of type l in sample unit i in year y; days

$$VS_{l,i,y} = VS_{rate,l} \times \frac{W_{bsl,l,i,y}}{1000} \quad \text{(Equation 8)}$$

Where:

$VS_{l,i,y}$ = Average volatile solids excretion per head for livestock type l in sample unit i in year y; kg volatile solids / (head * day)

$VS_{rate,l}$ = Default volatile solids excretion rate for livestock type l; kg volatile solids/(1000 kg animal mass * day)

$W_{bsl,l,i,y}$ = Average weight in the baseline scenario of livestock type l for sample unit i in year y; kg animal mass/head

1000 = Kg per 1000kg

8.16 Methane Emissions from Biomass Burning

If methane emissions from Biomass Burning are included per Table 3 the following equation must be used:

$$CH4bb_{bsl,i,y} = \frac{\frac{GWP_{CH4} \times \sum_{c=1}^{C} MB_{bsl,c,i,y} \times CF_c \times EF_{c,CH4}}{10^6}}{A_i} \quad \text{(Equation 9)}$$

Where:

$CH4bb_{bsl,i,y}$ = Methane emissions in the baseline scenario from biomass burning for sample unit i in year y; tCO2e/unit area

$MB_{bsl,c,i,y}$ = Mass of agricultural residues of type c burned in the baseline scenario or sample unit i in year y; kilograms

CF_c = Combustion factor for agricultural residue type c; proportion of pre-fire fuel biomass consumed

$EF_{c,CH4}$ = Methane emission factor for the burning of agricultural residue type c; g CH4/kg dry matter burnt

10^6 = Grams per tonne

8.17 Nitrous Oxide Emissions from Nitrogen Fertilizers and Nitrogen-Fixing Species

If nitrogen oxide emissions from Nitrogen Fertilizers and Nitrogen-Fixing species are included per Table 3 the following equation must be used:

$$N20soil_{bsl,i,y} = N20fert_{bsl,i,y} + {N20_{Nfix}}_{bsl,i,y} \qquad \text{(Equation 10)}$$

Where:

$N20soil_{bsl,i,y}$ = Direct and indirect nitrous oxide emissions due to nitrogen inputs to soils in the baseline scenario for sample unit i in year y; tCO2e/unit area

$N20fert_{bsl,i,y}$ = Nitrous oxide emissions due to fertilizer use in the baseline scenario for sample unit i in year y; tCO2e/unit area

${N20_{Nfix}}_{bsl,i,y}$ = Nitrous oxide emissions due to nitrogen fixing species use in the baseline scenario for sample unit i in year y; tCO2e/unit area

$$N20fert_{bsl,i,y} = N20fert_{bsl,direct,i,y} + N20fert_{bsl,indirect,i,y} \qquad \text{(Equation 11)}$$

Where:

$N20fert_{bsl,i,y}$ = Direct and indirect nitrous oxide emissions due to nitrogen inputs to soils in the baseline scenario for sample unit i in year y; tCO2e/unit area

$N20fert_{bsl,direct,i,y}$ = Nitrous oxide emissions due to direct fertilizer use in the baseline scenario for sample unit i in year y; tCO2e/unit area

$N20fert_{bsl,indirect,i,y}$ = Nitrous oxide emissions due to indirect fertilizer use in the baseline scenario for sample unit i in year y; tCO2e/unit area

i = Sample unit

Direct nitrous oxide emissions due to fertilizer use in the baseline scenario are quantified in Equation 12, Equation 13 and Equation 14.

$$N20fert_{bsl,direct,i,y} = ((FSN_{bsl,i,y} + FON_{bsl,i,y})) \times EF_{Ndirect} \times \frac{44}{28} \times GWP_{N2O})/A_i \qquad \text{(Equation 12)}$$

$$FSN_{bsl,i,y} = \sum_{SF} M_{bsl,SF,i,y} \times NC_{bsl,SF}$$

(Equation 13)

$$FON_{bsl,i,y} = \sum_{OF} M_{bsl,OF,i,y} \times NC_{bsl,OF}$$

(Equation 14)

Where:

$N20fert_{bsl,direct,i,y}$ = Nitrous oxide emissions due to direct fertilizer use in the baseline scenario for sample unit i in year y; tCO2e/unit area

$FSN_{bsl,i,y}$ = Baseline synthetic N fertilizer applied for sample unit i in year y; t N

$FON_{bsl,i,y}$ = Baseline organic N fertilizer applied for sample unit i in year y; t N

$EF_{Ndirect}$ = Emission factor for nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments and crop residues; t N2O-N/t N applied

GWP_{N2O} = Global warming potential for N2O

A_i = Area of sample unit i; unit area

SF = Synthetic N fertilizer type

OF = Organic N fertilizer type

$M_{bsl,SF,i,y}$ = Mass of baseline N containing synthetic fertilizer type SF applied for sample unit i in year y; t fertilizer

$M_{bsl,OF,i,y}$ = Mass of baseline N containing organic fertilizer type OF applied for sample unit i in year y; t fertilizer

$NC_{bsl,SF}$ = N content of baseline synthetic fertilizer type SF applied; t N/t fertilizer

$NC_{bsl,OF}$ = N content of baseline organic fertilizer type OF applied; t N/t fertilizer

Indirect nitrous oxide emissions due to fertilizer use in the baseline scenario are quantified in Equation 15, Equation 16 and Equation 17.

$$N20fert_{bsl,indirect,i,y} = \frac{N20fert_{bsl,volat,i,y} + N20fert_{bsl,leach,i,y}}{A_i} \quad \text{(Equation 15)}$$

$$N20fert_{bsl,volat,i,y} = \left(FSN_{bsl,i,y} \times FRAC_{GASF}\right) + \left(FON_{bsl,i,y} \times FRAC_{GASM}\right) \times EF_{Nvolat} \times \frac{44}{28} \times GWP_{N2O} \quad \text{(Equation 16)}$$

$$N20fert_{bsl,leach,i,y} = \left(FSN_{bsl,i,y} + FON_{bsl,i,y}\right) \times FRAC_{LEACH} \times EF_{Nleach} \times \frac{44}{28} \times GWP_{N2O} \quad \text{(Equation 17)}$$

Where:

$N20fert_{bsl,indirect,i,y}$ = Nitrous oxide emissions due to indirect fertilizer use in the baseline scenario for sample unit i in year y; tCO2e/unit area

$N20fert_{bsl,volat,i,y}$ = Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to fertilizer use for sample unit i in year y; tCO2e/unit area

$N20fert_{bsl,leach,i,y}$ = Indirect nitrous oxide emissions produced from leaching and runoff of N, in regions where leaching and runoff occurs, due to fertilizer use for sample unit i in year y; tCO2e/unit area

$FSN_{bsl,i,y}$ = Baseline synthetic N fertilizer applied for sample unit i in year y; t N

$FON_{bsl,i,y}$ = Baseline organic N fertilizer applied for sample unit i in year y; t N

$FRAC_{GASF}$ = Fraction of all synthetic N added to soils that volatilizes as NH3 and NOx; dimensionless

$FRAC_{GASM}$ = Fraction of all organic N added to soils and N in manure and urine deposited on soils that volatilizes as NH3 and NOx; dimensionless

$FRAC_{LEACH}$ = Fraction of N added (synthetic or organic) to soils and in manure and urine deposited on soils that is lost through leaching and runoff, in regions where leaching and runoff occurs; dimensionless. For wet climates[5] or in dry climate regions where irrigation (other than drip irrigation) is used, a value of 0.24 is applied. For dry climates, a value of zero is applied.

EF_{Nvolat} = Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces; t N2O-N /(t NH3-N + NOx-N volatilized)

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[5] Wet climates occur in temperate and boreal zones where the ratio of annual precipitation : potential evapotranspiration > 1, and tropical zones where annual precipitation > 1000 mm. Dry climates occur in temperate and boreal zones where the ratio of annual precipitation : potential evapotranspiration < 1, and tropical zones where annual precipitation < 1000 mm.

EF_{Nleach} = Emission factor for nitrous oxide emissions from leaching and runoff; t N2O-N / t N leached and runoff

If nitrous oxide emissions due to the use of N-fixing species are included in the project boundary per Table 3, they are quantified in the baseline scenario using Equation 18 and Equation 19.

$$N20_{{Nfix}_{bsl,i,y}} = \frac{\left(F_{CR,bsl,i,y} \times EF_{Ndirect} \times \frac{44}{28} \times GWP_{N2O}\right)}{A_i} \qquad \text{(Equation 18)}$$

Where:

$N20_{{Nfix}_{bsl,i,y}}$ = Nitrous oxide emissions due to the use of N-fixing species in the baseline scenario for sample unit i in year y; tCO2e/unit area

$F_{CR,bsl,i,y}$ = Amount of N in N-fixing species (above and below ground) returned to soils in the baseline scenario for sample unit i in year y; t N

$EF_{Ndirect}$ = Emission factor for nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments and crop residues; t N2O-N/t N applied

$\frac{44}{28}$ = Ratio of molecular weight of N2O to molecular weight of N applied to convert N2O-N emissions to N2O emissions

GWP_{N2O} = Global warming potential for N2O

A_i = Area of sample unit i; unit area

$$F_{CR,bsl,i,y} = \sum_{g=1}^{G} MB_{g,bsl,i,y} \times N_{content,g} \qquad \text{(Equation 19)}$$

Where:

$F_{CR,bsl,i,y}$ = Amount of N in N-fixing species (above and below ground) returned to soils in the baseline scenario for sample unit i in year y; t N

$MB_{g,bsl,i,y}$ = Annual dry matter, including aboveground and below ground, of N-fixing species g returned to soils for sample unit i in year y; t dm

$N_{content,g}$ = Fraction of N in dry matter for N-fixing species g; t N/t dm

g = Type of N-fixing species

i = Sample unit

8.18 Nitrous Oxide Emissions from Manure Deposition

If nitrogen oxide emissions from manure deposition are included per Table 3 the following equation must be used:

$$N20md_{bsl,i,y} = N20md_{bsl,direct,i,y} \times N20md_{bsl,indirect,i,y}$$ (Equation 20)

Where:

$N20md_{bsl,i,y}$ = Nitrous oxide emissions due to manure deposition in the baseline scenario for sample unit i in year y; tCO2e/unit area

$N20md_{bsl,direct,i,y}$ = Direct nitrous oxide emissions due to manure deposition in the baseline scenario for sample unit i in year y; tCO2e/unit area

$N20md_{bsl,indirect,i,y}$ = Indirect nitrous oxide emissions due to manure deposition in the baseline scenario for sample unit i in year y; tCO2e/unit area

$$N20md_{bsl,direct,i,y} = \frac{(\sum_{l=1}^{L} F_{bsl,manure,l,i,y} \times EF_{N20,md,l} \times \frac{44}{28} \times GWP_{N2O})}{A_i}$$ (Equation 21)

Where:

$F_{bsl,manure,l,i,y}$ = Amount of nitrogen in manure and urine deposited on soils by livestock type l in sample unit i in year y; tN

$EF_{N20,md,l}$ = Emission factor for nitrous oxide from manure and urine deposited on soils by livestock type l; kg N2O-N/kg N input

$$F_{bsl,manure,l,i,y} = \frac{[(P_{bsl,l,i,y} \times Nex_l) \times MS_{bsl,l,i,y}]}{1000}$$ (Equation 22)

Where:

$F_{bsl,manure,l,i,y}$ = Amount of nitrogen in manure and urine deposited on soils by livestock type l in sample unit i in year y; tN

$P_{bsl,l,i,y}$ = Baseline population of livestock type l in sample unit i in year y; head

Nex_l = Average annual nitrogen excretion per head of livestock type l; kg N/head/year

$MS_{bsl,l,i,y}$ = Baseline fraction of total annual N excretion for each livestock type l for sample unit i in year y that is deposited on the project area; %

$$N20md_{bsl,indirect,i,y} = \frac{\left(N20_{md_{bsl,volat,i,y}} + N20_{md_{bsl,leach,i,y}}\right)}{A_i}$$ (Equation 23)

Where:

$N20_{md\,bsl,volat,i,y}$ = Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to manure deposition for sample unit i in year y; tCO2e

$N20_{md\,bsl,leach,i,y}$ = Indirect nitrous oxide emissions produced from leaching and runoff of N, in regions where leaching and runoff occurs, as a result of manure deposition for sample unit i in year y. Equal to 0 where annual precipitation is less than potential evapotranspiration, unless irrigation is employed; tCO2e

$$N20md_{bsl,volat,i,y} = F_{bsl,manure,l,i,y} \times Frac_{GASM} \times EF_{Nvolat} \times \frac{44}{28} \times GWP_{N20}$$

(Equation 24)

Where:

$Frac_{GASM}$ = Fraction of all organic N added to soils and N in manure and urine deposited on soils that volatilizes as NH3 and NOx; dimensionless

EF_{Nvolat} = Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces; t N2O-N /(t NH3-N + NOx-N volatilized

$$N20md_{bsl,leach,i,y} = F_{bsl,manure,l,i,y} \times Frac_{LEACH} \times EF_{Nleach} \times \frac{44}{28} \times GWP_{N20}$$

(Equation 25)

Where:

$Frac_{LEACH}$ = Fraction of all organic N added to soils and N in manure and urine deposited on soils that is lost through leaching and runoff, in regions where leaching and runoff occurs; dimensionless. For wet climates[6] or in dry climate regions where irrigation (other than drip irrigation) is used, a value of 0.24 is applied. For dry climates, a value of zero is applied.

EF_{Nleach} = Emission factor for nitrous oxide emissions from leaching and runoff; t N2O-N / t N leached and runoff

8.19 Nitrous Oxide Emissions from Biomass Burning

If nitrogen oxide emissions from biomass burning are included per Table 3 the following equation must be used:

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[6] Wet climates occur in temperate and boreal zones where the ratio of annual precipitation: potential evapotranspiration > 1, and tropical zones where annual precipitation > 1000 mm. Dry climates occur in temperate and boreal zones where the ratio of annual precipitation : potential evapotranspiration < 1, and tropical zones where annual precipitation < 1000 mm.

$$N20bb_{bsl,i,y} = \frac{\sum_{c=1}^{C} MB_{bsl,c,i,y} \times EF_{c,N20} \times GWP_{N2O} \times CF_c}{10^6} / A_i \qquad \text{(Equation 26)}$$

Where:

$N20bb_{bsl,i,y}$ = Nitrous oxide emissions in the baseline scenario from biomass burning for sample unit i in year y; tCO2e/unit area

$MB_{bsl,c,i,y}$ = Mass of agricultural residues of type c burned in the baseline scenario or sample unit i in year y; kilograms

CF_c = Combustion factor for agricultural residue type c; proportion of pre-fire fuel biomass consumed

$EF_{c,N20}$ = Nitrous oxide emission factor for the burning of agricultural residue type c; g N2O/kg dry matter burnt

8.2 Project Removals and Emissions

Stock change/emissions resulting from agricultural management activities taking place in the project scenario are either calculated or modelled on the basis of monitored inputs. The estimation of emissions of CO2, CH4, and N2O in the project scenario from included sources must using the same equations in Section 8.1. For all equations, the subscript *bsl* must be substituted by *wp* to make clear that the relevant values are being quantified for the project scenario. Further, if livestock is included in the baseline, the minimum value allowed for the project is equal to the average value from the historical baseline period.

Quantification Approaches for GHG Removals

Quantification Approaches 1 & 3

Model inputs must be collected following guidance in Table 6 if the project is not using a SOCIALCARBON Approved Service Provider for this methodology. If the project is using a SOCIALCARBON Approved Service Provider for this methodology, the model inputs may vary depending on the model used.

Table 6: Guidance on collection of model inputs for the project scenario, where required by the model selected.

Model input category	Timing	Approach
Soil organic carbon and bulk density to calculate SOC stocks	Determined at project start via direct measurements at y = 0 or (back-) modeled to y = 0 from measurements collected within ±5 years of y = 0. Subsequent measurements are required every five years or more frequently.	Measured and modelled using SOCIALCARBON Approved Service Provider; or Directly measured via conventional analytical laboratory methods, e.g., dry combustion, or estimated via emerging technologies with known uncertainty following the criteria in Appendix 3:

		guidance on potential emerging technologies to measure SOC stocks and Appendix 5: Considerations for Approaching Uncertainty in Remote Sensing Measurements, every 5 years or less. See parameter table for $SOC_{wp,i,y}$
Soil properties (other than bulk density and soil organic carbon)	Determined ex ante	Measured or determined from published soil maps with known uncertainty. Estimates from direct measurements must: • Derived from representative (unbiased) sampling • Accuracy of measurements is ensured through adherence to best practices (to be determined by the project proponent and outlined in the monitoring plan)
Climate variables (e.g. precipitation and temperature)	Continuously monitored ex post	Measured for each model-specific meteorological input variable at its required temporal frequency (e.g., daily) model prediction interval. Measurements are taken at the closest continuously-monitored weather station, not exceeding 50 km of the sample field, or from a synthetic weather station (e.g. PRISM).
Land management activities	Monitored ex post	Required model inputs related to land management practices will be monitored and recorded for each project year, *y*. Information on land management practices will be monitored via consultation with, and substantiated with a signed attestation from, the farmer or landowner of the sample unit. Any quantitative information (e.g., discrete or continuous numeric variables) on land management practices must be supported by one or more forms of documented evidence pertaining to the selected sample field and relevant monitoring period (e.g., management logs, receipts or invoices, farm equipment specifications). Where possible, quantitative information can be evidenced through remote sensing imagery (e.g. hectares harvested). Units for quantitative information will be based on model input requirements.

Quantification Approach 2

Soil organic carbon stocks in the project scenario ($SOC_{wp,i,t}$) are calculated on an equivalent soil mass (ESM) basis by multiplication with the soil organic carbon content in each sample unit or stratum at time y-1 directly measured in each sample field. When bulk density is measured in a fixed depth approach, mass corrections can be applied to meet the ESM requirement.

A detailed description of SOC stock calculations with multiple soil depth increments along with spreadsheets and R scripts to standardize and facilitate calculations on an ESM basis are provided in (Wendt and Hauser, 2013) and (von Haden, Yang and DeLucia, 2020). SOC stock changes are calculated in equation 28.

Woody Biomass

Aboveground woody biomass must be included where project activities may significantly reduce the pool compared to the baseline. In all other cases aboveground woody biomass is an optional pool. Where included it is calculated using the *CDM A/R Tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* and *Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.*

Project Proponents are permitted to utilise emerging technology (e.g. remote sensing) with known uncertainty to measure changes in woody biomass. If this approach is taken, woody biomass must be measured both in the baseline and project scenario for the length of the project period using this method. 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.

Quantifying Total GHG Removals

$$TER_y = \Delta C_{soil,y} + \Delta C_{tree,y} + \Delta C_{shrub,y} \qquad \text{(Equation 27)}$$

Where:

$\Delta C_{soil,y}$ = Areal average GHG removals from increasing soil organic carbon in the project area in year y; tCO2e/unit area

$\Delta C_{tree,y}$ = Areal average GHG removals from increasing tree biomass in the project area in year y; tCO2e/unit area

$\Delta C_{shrub,y}$ = Areal average GHG removals from increasing shrub biomass in the project area in year y; tCO2e/unit area

Removals from increasing Soil Organic Carbon

$$\Delta C_{soil,i,y} = SOC_{wp,i,y} - SOC_{wp,i,y-1} \qquad \text{(Equation 28)}$$

Where:

$\Delta C_{soil,i,y}$ = Carbon dioxide emission removals from increasing soil organic carbon for sample i in year y; tCO2e/unit area

$SOC_{wp,i,y}$ = Carbon stocks in the Soil Organic Carbon pool in the project scenario for sample field i at the end of year y; tCO2e/unit area

$SOC_{wp,i,y-1}$ = Carbon stocks in the Soil Organic Carbon pool in the project scenario for sample field i at the end of year $y-1$; tCO2e/unit area

The initial SOC is the same in both the baseline and project scenarios at the outset of the project (i.e. $SOC_{wp,i,0} = SOC_{bsl,i,0}$); as a result, the first calculation of Equation 28 on sample unit *i* simplifies to $SOC_{wp,i,y} - SOC_{bsl,i,y}$.

Where the period between time y and time y-1 spans multiple calendar years, the project proponent shall pro-rate the results of Equation 28 the relevant vintages according to the number of days in the monitoring period contained within each vintage. For example, if the total stock change is measured across exactly three calendar years, then one third of the stock change would be attributed to each vintage. When the previous year (y-1) is the baseline / validation year, $C_{tree,y-1}$ and $C_{shrub,y-1}$ must be the baseline carbon stocks calculated.

Removals from increasing Tree Biomass

$$\Delta C_{tree,y} = C_{tree,y} - C_{tree,y-1} \qquad \text{(Equation 29)}$$

Where:

$\Delta C_{tree,y}$ = Areal average carbon dioxide emission removals from increasing tree biomass in year y; tCO2e/unit area

$C_{tree,y}$ = Areal average project scenario carbon stock in tree biomass in year y; tCO2e/unit area

$C_{tree,y-1}$ = Areal average baseline scenario carbon stock in tree biomass in year $y-1$; tCO2e/unit area

Removals from increasing Shrub Biomass

$$\Delta C_{shrub,y} = C_{shrub,y} - C_{shrub,y-1} \qquad \text{(Equation 30)}$$

Where:

$\Delta C_{shrub,y}$ = Areal average carbon dioxide emission removals from increasing shrub biomass in year y; tCO2e/unit area

$C_{shrub,y}$ = Areal average project scenario carbon stock in shrub biomass in year y; tCO2e/unit area

$C_{shrub,y-1}$ = Areal average baseline scenario carbon stock in shrub biomass in year $y-1$; tCO2e/unit area

Quantifying Total Project Emissions

Any project emissions that have increased over the project monitoring period must be quantified and deducted from the total emission removals measured.

Increases in emissions of less than 5% are deemed negligible and can have the default value of zero. The following equations outline how increases in emissions from the GHG emission sources outlined in section 5 should be quantified.

$$PE_y = \Delta C02_{ff_y} + \Delta CH4_{ent_y} + \Delta CH4_{md_y} + \Delta CH4_{bb_y} + \Delta N20_{soil_y} + \Delta N20_{bb_y} + \Delta N20_{md_y}$$

(Equation 31)

Where:

PE_y = Total project emissions in year y; tCO2e/unit area

$\Delta C02_{ff_y}$ = Areal average carbon dioxide emissions from fossil fuel combustion in year y; tCO2e/unit area

$\Delta CH4_{ent_y}$ = Areal average methane emissions from enteric fermentation in year y; tCO2e/unit area; tCO2e/unit area

$\Delta CH4_{md_y}$ = Areal average methane emissions from manure deposition in year y; tCO2e/unit area; tCO2e/unit area

$\Delta CH4_{bb_y}$ = Areal average methane emissions from biomass burning in year y; tCO2e/unit area; tCO2e/unit area

$\Delta N20_{soil_y}$ = Areal average nitrous oxide emissions from nitrification in year y; tCO2e/unit area; tCO2e/unit area

$\Delta N20_{bb_y}$ = Areal average nitrous oxide emissions from biomass burning in year y; tCO2e/unit area; tCO2e/unit area

Emissions from fossil fuel combustion

$$\Delta C02_{ff_{i,y}} = C02_{ff_{wp,i,y}} - C02_{ff_{bsl,i,y}}$$

(Equation 32)

Where:

$\Delta C02_{ff_{i,y}}$ = Carbon dioxide emissions from fossil fuel combustion for sample unit i in year y; tCO2e/unit area

$C02_{ff_{wp,i,y}}$ = Carbon dioxide emissions from fossil fuel combustion in the project scenario for sample unit i in year y; tCO2e/unit area

$C02_{ff_{bsl,i,y}}$ = Carbon dioxide emissions from fossil fuel combustion in the baseline scenario for sample unit i in year y; tCO2e/unit area

Emissions from enteric fermentation

$$\Delta CH4_{ent_{i,y}} = CH4_{ent_{wp,i,y}} - CH4_{ent_{bsl,i,y}}$$ (Equation 33)

Where:

$\Delta CH4_{ent_{i,y}}$ = Methane emissions from livestock enteric fermentation for sample unit i in year y; tCO2e/unit area

$CH4_{ent_{wp,i,y}}$ = Methane emissions from livestock enteric fermentation in the project scenario for sample unit i in year y; tCO2e/unit area

$CH4_{ent_{bsl,i,y}}$ = Methane emissions from livestock enteric fermentation in the baseline scenario for sample unit i in year y; tCO2e/unit area

Emissions from manure deposition

$$\Delta CH4_{md_{i,y}} = CH4_{md_{wp,i,y}} - CH4_{md_{bsl,i,y}}$$ (Equation 34)

Where:

$\Delta CH4_{md_{i,y}}$ = Methane emissions from manure deposition for sample unit i in year y; tCO2e/unit area

$CH4_{md_{wp,i,y}}$ = Methane emissions from manure deposition in the project scenario for sample unit i in year y; tCO2e/unit area

$CH4_{md_{bsl,i,y}}$ = Methane emissions from manure deposition in the baseline scenario for sample unit i in year y; tCO2e/unit area

Methane emissions from biomass burning

$$\Delta CH4_{bb_{i,y}} = CH4_{bb_{wp,i,y}} - CH4_{bb_{bsl,i,y}}$$ (Equation 35)

Where:

$\Delta CH4_{bb_{i,y}}$ = Methane emissions from biomass burning for sample unit i in year y; tCO2e/unit area

$CH4_{bb_{wp,i,y}}$ = Methane emissions from biomass burning in the project scenario for sample unit i in year y; tCO2e/unit area

$CH4_{bb_{bsl,i,y}}$ = Methane emissions from biomass burning in the baseline scenario for sample unit i in year y; tCO2e/unit area

Nitrous Oxide emissions from biomass burning

$$\Delta N2O_{bb_{i,y}} = N2O_{bb_{wp,i,y}} - N2O_{bb_{bsl,i,y}}$$ (Equation 36)

Where:

$\Delta N2O_{bb_{i,y}}$ = Nitrous oxide emissions from biomass burning for sample unit i in year y; tCO2e/unit area

$N2O_{bb_{wp,i,y}}$ = Nitrous oxide emissions from biomass burning in the project scenario for sample unit i in year y; tCO2e/unit area

$N2O_{bb_{bsl,i,y}}$ = Nitrous oxide emissions from biomass burning in the baseline scenario for sample unit i in year y; tCO2e/unit area

Nitrous Oxide emissions from nitrification/denitrification

$$\Delta N2O_{soil_{i,y}} = N2O_{soil_{wp,i,y}} - N2O_{soil_{bsl,i,y}} \quad \text{(Equation 37)}$$

Where:

$\Delta N2O_{soil_{i,y}}$ = Nitrous oxide emissions from nitrification/denitrification for sample unit i in year y; tCO2e/unit area

$N2O_{soil_{wp,i,y}}$ = Nitrous oxide emissions from nitrification/denitrification in the project scenario for sample unit i in year y; tCO2e/unit area

$N2O_{soil_{bsl,i,y}}$ = Nitrous oxide emissions from nitrification/denitrification in the baseline scenario for sample unit i in year y; tCO2e/unit area

Nitrous Oxide emissions from manure deposition

$$\Delta N2O_{md_{i,y}} = N2O_{md_{wp,i,y}} - N2O_{md_{bsl,i,y}} \quad \text{(Equation 38)}$$

Where:

$\Delta N2O_{md_{i,y}}$ = Nitrous oxide emissions from manure deposition for sample unit i in year y; tCO2e/unit area

$N2O_{md_{wp,i,y}}$ = Nitrous oxide emissions from manure deposition in the project scenario for sample unit i in year y; tCO2e/unit area

$N2O_{md_{bsl,i,y}}$ = Nitrous oxide emissions from manure deposition in the baseline scenario for sample unit i in year y; tCO2e/unit area

8.3 Leakage

Three potential sources of Leakage are applicable to the project:

- A reduction in productivity.
- An increase in the use of fuel wood and/or fossil fuels for non-renewable sourcing for cooking and heating purposes due to the decrease in the use of manure and/or residuals as an energy source.

- If new manure, compost or biosolids are applied in the project that was were not applied in the historical baseline period.

$$LE_y = LE_{Productivity,y} + LE_{Fuel,y} + LE_{Biosolids,y} \quad \text{(Equation 39)}$$

Where:

LE_y = GHG emissions due to leakage in year y; tCO2e

$LE_{Productivity,y}$ = GHG emissions due to leakage from the reduction in productivity in year y; tCO2e

$LE_{\mathrm{Fuel},y}$ = GHG emissions due to leakage from non-renewable fuel sourcing in year y; tCO2e

$LE_{\mathrm{Biosolids},y}$ = GHG emissions due to leakage from biosolids in year y; tCO2e

Estimation of Leakage from a reduction in productivity

Market leakage is likely to be negligible because the land in the project scenario remains in agricultural production. Further, producers are unlikely to implement and maintain management practices that result in productivity declines, since their livelihoods depend on crop harvests as a source of income.

Nevertheless, to ensure leakage is not occurring, the following steps must be completed every 10 years:

Step 1: Demonstrate that the productivity of each crop/livestock product has not declined by more than 5% in the project scenario by comparing:

1. Average with-project productivity (excluding years with extreme[7] weather events) of each crop/livestock product to average pre-project productivity of the same crop/livestock product using Equation 40;

   Or

2. The ratio of average baseline productivity to regional productivity at time *t* to the average ratio of project productivity to regional productivity at time *t* + 10 years, by crop/livestock product, using Equation 41 and regional data from government (e.g., USDA Actual Production History (APH) data), industry, published, academic or international organization (e.g., FAO) sources[8].

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[7] Extreme weather events are defined as temperature, drought or precipitation events falling in the upper or lower tenth percentile of historical multi-year records for the project location (NOAA). Furthermore, tropical storms affecting the project location (e.g., hurricanes, typhoons and cyclones) are considered extreme weather events, as is any time a weather-related insurance claim is awarded.

[8] Using this approach, a productivity decline of 10% in the project would be acceptable as long as a corresponding productivity decline of 10% was also observed in the regional data. This ensures that external factors such as reduced rainfall that can impact productivity in a region are fairly accounted for. Further, this approach prevents producers whose baseline productivity is lower than regional averages due to lack of access to inputs (e.g., agrochemicals), knowledge or some other factor from being unfairly penalized.

$$\Delta P = \left(\frac{P_{wp,p} - P_{bsl,p}}{P_{bsl,p}}\right) \times 100 \qquad \text{(Equation 40)}$$

Where:

ΔP = Change in productivity; percent

$P_{wp,p}$ = Average productivity for product P during the project period; productivity per hectare or acre

$P_{bsl,p}$ = Average productivity for product P during the historical baseline period; productivity per hectare or acre

P = Crop/livestock product

$$\Delta PR = \left(\frac{P_{wp,p}}{PR_{wp,p}} - \frac{P_{bsl,p}}{PR_{bsl,p}}\right) \times 100 \qquad \text{(Equation 41)}$$

Where:

ΔPR = Change in productivity ratio per hectare or acre; percent

$P_{wp,p}$ = Average productivity for product P during the project period; productivity per hectare or acre

$P_{bsl,p}$ = Average productivity for product P during the historical baseline period; productivity per hectare or acre

$PR_{wp,p}$ = Average regional productivity for product P during the same years as the project period; productivity per hectare or acre

$PR_{bsl,p}$ = Average regional productivity product P during the same years as the historical baseline period; productivity per hectare or acre

P = Crop/livestock product

With-project productivity averages must be based on data collected in the previous 10 years. In other words, productivity averages cannot include data that is more than 10 years old. If productivity has improved, stayed constant or declined by less than 5% for a crop/livestock product, no further action is needed. If a reduction in productivity of greater than 5% is observed in one or more crop/livestock product, complete Step 2 for these products.

Step 2: Determine whether the crop/livestock productivity decline was caused by a short-term change in productivity, by repeating the calculation in Step 1 excluding all data inputs from the first three years of project implementation on a farm. If the with-project productivity of the crop/livestock product with the first three years removed is within 5% of the baseline productivity of the same crop/livestock product, no further action is needed[9].

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[9] Initial implementation of improved regenerative land management practices may lead to some declines in productivity as the producer adjusts their operation. By demonstrating that more recent years are within the 5% threshold, Step 2 shows that producers have overcome any early productivity declines.

If a reduction in productivity of greater than 5% is still observed in one or more crop/livestock product(s), complete Step 3 for these products.

Step 3: Determine whether the productivity decline is limited to a certain combination of factors by stratifying the analysis by:

1. Practice change category,
2. Practice change category combinations,
3. Crop type,
4. Soil type, and/or
5. Climatic zone.

If the productivity decline is limited to a certain combination of factors, then that combination becomes ineligible for future crediting. For example, if a 10% decline in corn yields was observed and through stratification it was shown that the yield decline was linked to no-tillage practices, then no-tillage practices on corn fields would no longer be eligible for future crediting. If the project proponent is unable to isolate the source(s) of leakage through stratification, then the entire crop/livestock product becomes ineligible for future crediting.

Estimation of Leakage from non-renewable fuel sourcing

The one potential source of leakage is an increase in the use of fuel wood and/or fossil fuels from non-renewable sources for cooking and heating purposes due to the decrease in the use of manure and/or residuals as an energy source.

Leakage due to the increase in the use of fuel wood from non-renewable sources for cooking and heating purposes may be a significant source of leakage if manure or other agricultural residuals used for cooking and heating are transferred to the fields as part of the project. In the project, this could be minimized by the introduction of woody perennials for fuel in the landscape and/or improvement of energy efficiency of biomass for cooking and heating. In situations of this form of leakage, the leakage from a switch to non-renewable biomass use, $LE_{Fuel,y}$, is calculated in accordance with equation 42 which is adapted from the *CDM small scale methodology AMS-I.E. Switch from Non-Renewable Biomass for Thermal Applications by the User*.

The project must conduct a survey to assess whether or not non-renewable biomass from outside the project or fossil fuels are used for the purpose of cooking or heating by the surveyed project households to replace the biomass diverted to agricultural fields. If the survey data shows that 10% or fewer project households use non-renewable biomass from outside the project or fossil fuels to replace the biomass diverted to agricultural fields, then the leakage is considered insignificant and ignored.

However, where this is significant, leakage due to switch to fossil fuels (LFF_t) shall be estimated in accordance with equation 44.

$$LE_{Fuel,y} = LNRB_y + LFF_y \qquad \text{(Equation 42)}$$

Where:

$LE_{\text{Fuel},y}$ = GHG emissions due to leakage from non-renewable fuel sourcing in year y; tCO2e

$LNRB_y$ = Leakage from a switch to non-renewable biomass use in year y; tCO2e

LFF_y = Leakage from switch to fossil fuel in year y; tCO2e

$$LNRB_y = B_{Biomass,y} \times fNRB \times NCV_{biomass} \times EF_{fossil\ fuel} \quad \text{(Equation 43)}$$

Where:

$LNRB_y$ = Leakage from a switch to non-renewable biomass use in year y; tCO2e

$B_{Biomass,y}$ = Quantity of biomass from outside the project that replaces biomass used for cooking/heating diverted to agricultural system in year y; tonnes

$fNRB$ = Fraction of non-renewable biomass from outside the project in year$y$; percent

$NCV_{biomass}$ = Net calorific value of the non-renewable biomass from outside the project in year y

$EF_{fossil\ fuel_y}$ = Emission factor of fossil fuel as substitute for non-renewable biomass in year y

$$LFF_y = B_{fossil\ fuel,y} \times NCV_{fossil\ fuel} \times EF_{fossil\ fuel} \quad \text{(Equation 44)}$$

Where:

LFF_y = Leakage from switch to fossil fuel in year y; tCO2e

$B_{fossil\ fuel,y}$ = Quantity of fossil fuel that replaces biomass used for cooking/heating diverted to agricultural system in year y; tonnes

$NCV_{fossil\ fuel}$ = Net calorific value of the fossil fuel that is used as substitution in year y

$EF_{fossil\ fuel_y}$ = Emission factor of fossil fuel as substitute for non-renewable biomass in year y

Estimation of Leakage from biosolids

If new[10] manure, compost or biosolids are applied in the project that were not applied in the historical baseline period, there is a risk of activity shifting leakage. To account for this type of leakage, a deduction must be applied unless:

1. The manure or compost applied in the project is produced on-site from farms within the project area;

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[10] In this context, "new" refers to manure application to fields which did not have manure applied during the historical baseline period.

2. The manure is documented to have been diverted from an uncontrolled anaerobic lagoon, pond, tank or pit;[11] from which there is no recovery of methane for generation of heat and/or electricity, nor use as soil amendment; or
3. The manure, compost or biosolids is documented to not have been used as a soil amendment.

The deduction represents the portion of the manure, compost or biosolids carbon which remains on the project area without degrading during the project term and which would have otherwise been applied to agricultural land outside of the project area.

Equation 45 estimates the SOC increase from imported manure, compost or biosolids application activities, reducing the total amount of carbon applied to 12% per a global manure-C retention coefficient sourced from Maillard and Angers (2014). While derived for manure, the equation is conservatively applied to compost or biosolids for the purposes of this methodology.

$$LE_{Biosolids,y} = \sum_{l} (M_{manure_{prj,l,y}} \times CC_{prj,l,y} \times 0.12 \times \frac{44}{12}) \qquad \text{(Equation 45)}$$

Where:

$LE_{Biosolids,y}$ = GHG emissions due to leakage from biosolids in year y; tCO2e

$\mathrm{M}_{manure_{prj,l,y}}$ = Mass of manure applied as fertilizer on the project area from livestock type l in year y; tonnes

$CC_{prj,l,y}$ = Carbon content of manure applied as fertilizer on the project area from livestock type l in year y; fraction

0.12 = Fraction of manure carbon expected to remain in the soils on the project area by the end of the project term ; fraction

$\frac{44}{12}$ = Conversion from carbon to carbon dioxide equivalent; tC/tCO2e

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[11] Where manure is diverted for field application rather than stored anaerobically in an uncontrolled, anaerobic lagoon, pond, tank or pit, the avoided methane emissions will far outweigh the SOC impacts. If manure is temporarily stored prior to field application, the storage should occur under aerobic conditions in stocks or piles. For definitions of manure storage and management systems, refer to table 10.18 of Chapter 10 of the 2019 Refinement to the IPCC Guidelines (IPCC, 2019).

8.4 Net GHG Emission Removals

Net GHG emission removals are calculated using the following equation:

$$NER_y = (TER_y \times (1 - UNC_y)) - PE_y - LE_y \quad \text{(Equation 46)}$$

Where:

NER_y = Net Emission Removals in year y; tCO2e

TER_y = Total project GHG removals in year y; tCO2e

PE_y = Total project GHG emissions in year y; tCO2e

LE_y = Leakage of emissions associated with the project in year y; tCO2e

UNC_y = Total uncertainty in project GHG removals in year y; percent

8.5 Uncertainty

Key sources of uncertainty accounted for are sample error and, where models are applied, measurement error of model inputs, model prediction error and model input error. Uncertainty in area estimation is addressed via complete (and accurate) GIS boundaries of the project area, applying QA/QC procedures specified in the parameter table for Ai.

Estimators of uncertainty provided below assume simple random sampling with replacement with a two-stage sample design, represented by sample points (e.g., points where soil cores are taken) within sample units (e.g., sample fields). Other unbiased sample designs (e.g., stratified samples, variable probability samples, further multi-stage samples) may also be employed, and estimators of variance reconfigured to permit un-biased estimation.

Under this methodology project emissions are estimated using default values/published data therefore the standard error for that source is set equal to zero.

8.5.1 Changes in woody biomass

The project proponent shall use the CDM EB approved *General Guidelines for Sampling and Surveys for Small-Scale CDM Project Activities* with a view to reducing uncertainty of model input parameters. The generation of model parameters follows the standard procedures on surveys and quality assurance in the collection and organization of data. In addition, the project proponent will calculate uncertainty based on the guidance provided in the CDM tool "*CDM A/R Tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities and Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.*"

If the changes in woody biomass are measured through remote sensing with a known uncertainty, the project proponent must discount any calculated values with the known uncertainty. The known uncertainty and discounts applied must be documented in the Project Description and Monitoring reports.

8.5.2 Soil Organic Carbon

8.5.2.1 Quantification Approach 1: Measure and Model

Model prediction error is quantified from paired modelled and direct-re-measured sites in an experimental sampling regime.

Data for quantifying model prediction error may be sourced from studies conducted external to the project area and should be from the same datasets used to validate the model. Alternatively, model prediction error is calculated using independent validation datasets per the processes outlined in VMD0053 or SCD0001.

$$S^2_{model,\Delta SOC,y} = \sigma_{\Delta SOC,y}\sqrt{2(1-\rho_{\Delta SOC}} \qquad \text{(Equation 47)}$$

Where:

$S^2_{model,\Delta SOC,y}$ = (Approximate) standard error for the change in SOC carbon stocks due to model prediction error at time y; tCO2e/unit area

$\sigma_{\Delta SOC,y}$ = Standard deviation of the modelled change in SOC carbon stocks at time y; tCO2e/unit area

$\rho_{\Delta SOC}$ = Correlation coefficient of model errors in the project scenario and model errors in the baseline scenario SOC pool; dimensionless

If the SOC stock is directly remeasured, then $S^2_{model,\Delta SOC,y} = \sigma_{\Delta SOC,y}$

If the amount of data for quantifying model prediction error varies significantly among crops, soil texture, and climate zones, then a model prediction error could be estimated for groups of similar sites (e.g., based on a stratification applied to the fields in the project and to the sites in the validation data, or based on a Gaussian Process fit to the validation data with biophysical variables, management practices, and/or other variables as predictors). That way, a model prediction error can be assigned to each sample point i: $S^2_{model,\Delta SOC,i,y}$. Under this scenario, $S^2_{model,\Delta SOC,y}$ is the model error variance for the population, estimated from the $S^2_{model,\Delta SOC,i,y}$ using the sample design used. For example, for a simple random sample or for the self-weighting two-stage design described below, $S^2_{model,\Delta SOC,y}$ is an average of the $S^2_{model,\Delta SOC,i,y}$ across i [see Cochran (1977, eq. 13.39)].

Model input measurement error

Measurement errors of model inputs are automatically captured by the estimate of sample error (discussed below), provided that the measurement errors are uncorrelated across sample points [see, e.g., Cochran (1977, p. 382); de Gruijter et al. (2006, p. 82); Som (1995, p. 438)]. QA/QC procedures for model inputs ensure that model inputs are sufficiently accurate and that measurement errors are uncorrelated with each other (see model input requirements in Table 5 and Table 6).

Sample and measurement error

Here, we give an example of a two-stage design with first-stage units chosen with probability proportional to their acreage (with replacement) and with second-stage units chosen with simple random sampling (with replacement). For example, the first-stage units could be fields that are tiled with a fine grid; the second-stage units are tiles within the grid, and the tiles all have the same area. This design could be modified in many ways, for example by assigning fields to strata, or by eliminating fields as a sampling unit and instead creating strata of tiles. In the first stage, n out of N fields are selected with probability proportional to their acreage with replacement. (If a field is chosen multiple times, then tiles are independently selected from that field multiple times.) Subsequent calculations are simplified by making the probability of selecting field i equal to its area A_i divided by the total area A_0 of all fields, i.e., probability proportional to size (PPS) sampling:

$$\pi_i = \frac{A_i}{A_0}$$

Within each selected field i, secondary sampling units (m_i) are chosen with simple random sampling with replacement. The estimator of the emissions reduction averaged across all tiles is the simple (unweighted) average across all sampled fields and sampled tiles [Som (1995), eq. 16.18; Cochran (1977), eq. 11.39]:

$$\overline{\Delta SOC_{y,unbiased}} = \frac{1}{n}\sum_{n=1}^{n}\overline{\Delta SOC_{i,y}} = \frac{1}{n}\sum_{n=1}^{n}\frac{1}{m_i}\sum_{k=1}^{m_i}\Delta SOC_{i,k,y} \qquad \text{(Equation 48)}$$

Where:

$\Delta SOC_{y,unbiased}$ = Areal average unbiased estimator of emissions removals of SOC in year y; tCO2e/unit area

$\Delta SOC_{i,y}$ = Areal average emissions removals of SOC year y in field i, computed as the average across the sample points in field i (areal average); tCO2e/unit area

$\Delta SOC_{i,k,y}$ = Estimated emissions removals of SOC in year y in field i, tile k (summed across the whole reporting period for field i, tile k in year y); tCO2e/unit area

n = Number of primary sampling units (fields) selected to be sampled

m_i = Number of secondary sampling units (tiles) selected to be sampled within field i

k = Secondary sampling unit within a primary sampling unit

i = Primary sampling unit (field)

Ignoring model errors, an unbiased estimator of the variance of $\Delta SOC_{y,unbiased}$ is from [Som (1995), eq. 16.19; Cochran (1977), eq. 11.40],

$$S^2_{sampled,\Delta SOC,y} = \frac{\sum_{i=1}^{n}(\Delta SOC_{i,y} - \Delta SOC_{y,unbiased})^2}{n(n-1)}$$ (Equation 49)

Where:

$S^2_{sampled,\Delta SOC,y}$ = (Approximate) standard error in ΔSOC carbon stocks due to sample error at time y; tCO2e/unit area

$\Delta SOC_{y,unbiased}$ = Areal average unbiased estimator of emissions removals of SOC in year y; tCO2e/unit area

$\Delta SOC_{i,y}$ = Areal average emissions removals of SOC year y in field i, computed as the average across the sample points in field i (areal average); tCO2e/unit area

n = Number of primary sampling units (fields) selected to be sampled

To fix the amount of work in each field, set m_i equal to constant m across all fields. Then the design becomes “self-weighting,” and Equation 49 simplifies to an average across all measurements, $\Delta SOC_{y,unbiased} = \frac{1}{n\,m}\sum_{i=1}^{n}\sum_{k=1}^{m}\Delta SOC_{i,k,y}$ where $\Delta SOC_{i,k,y}$ is the estimated emissions removals from changes in SOC carbon stock at point k in field i.

Combined sample and model error

To incorporate model errors, we assume that they are uncorrelated with the measurements in the sample, and we assume that model errors are independent across samples. Then by [Cochran (1977), eq. 13.39; Som (1995), eq. 25.10], the variance of $\Delta SOC_{y,unbiased}$ incorporating sample uncertainty, lab measurement uncertainty, and model prediction uncertainty is:

$$S^2_{\Delta SOC_y} = S^2_{sampled,\Delta SOC,y} + \frac{S^2_{model,\Delta SOC,y}}{n \times m}$$

Where:

$S^2_{\Delta SOC_y}$ = Variance of the estimate of mean emission removals from changes in SOC carbon stocks at year y; (tCO2e/unit area)^2

$S^2_{sampled,\Delta SOC,y}$ = Areal average unbiased estimator of emissions removals of SOC in year y; tCO2e/unit area

$S^2_{model,\Delta SOC,y}$ = Areal average emissions removals of SOC year y in field i, computed as the average across the sample points in field i (areal average); tCO2e/unit area

n = Number of primary sampling units (e.g. fields) selected to be sampled

m = Number of secondary sampling units (e.g. tiles) selected to be sampled within primary sampling units (e.g. fields)

When stock change in soil organic carbon is periodically directly re-measured in the project scenario, model (input and prediction error) uncertainty is only accounted for in the baseline scenario.

8.5.2.2 Quantification Approach 2: Measure and Re-Measure

For Quantification Approach 2, uncertainty is restricted to sample error around stock change in the project scenario.

The weighted mean standard error of the mean SOC carbon stock in the project area shall be calculate by summing the total standard error calculated for each sample unit i. This will be calculated by calculating the standard error per sample unit i as a percentage of the total project area A_0 as seen below:

$$S^2_{\overline{SOC_{i,y}}} = \frac{\sigma_{\overline{SOC,i,y}}}{\sqrt{n_i}} \times \frac{A_i}{A_0} \qquad \text{(Equation 50)}$$

Where:

$S^2_{\overline{SOC_{i,y}}}$ = Standard error in mean SOC Carbon stock measured in the sample unit i: tCO2e/unit area

$\sigma_{\overline{SOC,i,y}}$ = Standard deviation in mean SOC carbon stock measured in sample unit i: tCO2e

n_i = Number of samples taken in sample unit i

A_i = Total area of sample unit i; hectares / acres

A_0 = Total project area; hectares / acres

The standard error of the mean soil carbon stock change is calculated as:

$$S^2_{\overline{\Delta SOC_y}} = \frac{1}{n}\Big((S^2_{\overline{ps,y}} + S^2_{\overline{ps,y-1}} - 2Cov\big(SOC_{ps,y}, SOC_{ps,y-1}\big)\Big) \qquad \text{(Equation 51)}$$

Where:

$S^2_{\overline{\Delta SOC_y}}$ = The variance of the mean difference in SOC stocks in year y; (tCO2e/unit area)^2

$S^2_{\overline{ps,y}}, S^2_{\overline{ps,y-1}}$ = The variances of mean SOC stocks for the project site at the current time, for the project site at the previous time; (tCO2e/unit area)^2

$2Cov\big(SOC_{ps,y}, SOC_{ps,y-1}\big)$ = The covariance of between the SOC stocks for the project site at the current and previous time; (tCO2e/unit area)^2

n = Number of primary sampling units (fields) selected to be sampled

8.5.2.3 Quantification Approach 3: Modelled

Project proponents using Quantification Approach 3 to measure changes in Soil Organic Carbon stocks must use models with a known uncertainty. To total uncertainty using Quantification Approach 3 will be the combined model uncertainty and uncertainty of the model input parameters.

The project proponent shall use the *CDM EB approved General Guidelines for Sampling and Surveys for Small-Scale CDM Project Activities* with a view to reducing uncertainty of model input parameters.

If the project area is stratified, the sampling effort should represent the relevant strata in the sample frame. Where there is no specific survey guidance from national institutions, the project proponent shall use a precision of 15% at the 95% confidence level as the criteria for reliability of sampling efforts. This reliability specification shall be applied to determine the sampling requirements for assessing parameter values. The sampling intensity could be increased to ensure that the model parameters (where estimated) lead to the achievement of a desired precision of 15% at the 95% confidence level for the estimate of greenhouse gas emission removal from the project. The project proponent should calculate the soil model response using the model input parameters with the upper and lower confidence levels. The range of model responses demonstrates the uncertainty of the soil modelling.

Step 1: Calculate the values for all input parameters at the upper and lower confidence limit.

Calculate the mean, $\overline{X_p}$ and standard deviation, σ_p for all parameters estimated, and then the standard error in the mean is given by:

$$SE_p = \frac{\sigma_p}{\sqrt{n_p}} \quad \text{(Equation 52)}$$

Where:

SE_p = Standard error in the mean of parameter p in year y

σ_p = Standard deviation of parameter p in year y

n_p = Number of samples used to calculate the mean and standard deviation of parameter p

Assuming that values of the parameter are normally distributed about the mean, the minimum and maximum values for the parameters are given by:

$$P_{min} = \overline{X_p} - 1.96 \times SE_p \quad \text{(Equation 53)}$$

$$P_{max} = \overline{X_p} + 1.96 \times SE_p \quad \text{(Equation 54)}$$

Where:

P_{min} = The minimum value of the parameter at the 95% confidence interval

P_{max} = The maximum value of the parameter at the 95% confidence interval

Step 2: Calculate the project removals due to changes in soil organic carbon with the minimum and maximum values of the input parameters

The project removals due to changes in soil organic carbon using the minimum and maximum values of the parameters is given by:

$$\Delta C_{soil,y,min} = Model_{SOC}\{P_{min}\} \quad \text{(Equation 55)}$$

$$\Delta C_{soil,y,max} = Model_{SOC}\{P_{max}\} \quad \text{(Equation 56)}$$

Where:

$\Delta C_{soil,y,min}$ = The minimum value of project removals due to changes in soil organic carbon at the 95% confidence interval

$\Delta C_{soil,y,max}$ = The maximum value of project removals due to changes in soil organic carbon at the 95% confidence interval

Step 3: Calculate the uncertainty in the model output

The uncertainty in the output model is given by:

$$UNC_{Soil,y,inputs} = \frac{(\Delta C_{soil,y,max} - \Delta C_{soil,y,min})}{2 \times \Delta C_{soil,y}} \quad \text{(Equation 57)}$$

To account for the lack of physical soil samples to ‘True-Up’ the modelled estimates, an additional 10% discount must be applied. The total uncertainty for quantification approach 3 is as follows:

$$UNC_{Soil,y} = UNC_{y,inputs} + UNC_{y,model} + 10\% \quad \text{(Equation 58)}$$

Where:

$UNC_{Soil,y}$ = Total uncertainty for soil carbon stocks; percent

$UNC_{y,inputs}$ = Uncertainty of model input parameters; percent

$UNC_{y,model}$ = Known uncertainty of model used; percent

See Appendix 5: Considerations for Approaching Uncertainty in Remote Sensing Measurements *for* key considerations for approaching uncertainty in remote sensing measurements.

8.5.3 Total uncertainty deduction

$$UNC_y = MIN\left(100\%, MAX\left(0, \frac{T\sqrt{(S^2_{\Delta SOC_y} + S^2_{\Delta tree_y} + S^2_{\Delta shrub_y})}}{\overline{\Delta CO2_y}} - 15\%\right)\right) \quad \text{(Equation 59)}$$

Where:

UNC_y = Total uncertainty; percent

T = Critical value of a student's t-distribution for significance level α = 0.05 (i.e., a 1 − α = 95% confidence interval) and the degrees of freedom df appropriate for the design used (e.g., df = n − 1 for a simple random sample of n sample units)

$\overline{\Delta \mathrm{CO2}_t}$ = Areal average carbon dioxide emission removals in year y; t CO2e/unit area

$S^2_{\overline{\Delta SOC_y}}$ = Variance of the estimate of mean emission removals from Soil in year y; (tCO2e/unit area)^2

$S^2_{\overline{\Delta \mathrm{tree}_y}}$ = Variance of the estimate of mean emission removals from Trees in year y; (tCO2e/unit area)^2

$S^2_{\overline{\Delta \mathrm{shrub}_y}}$ = Variance of the estimate of mean emission removals from Shrubs in year y; (tCO2e/unit area)^2

15% = Threshold beyond which there is an uncertainty deduction

9. Monitoring

Where discretion exists in the selection of a value for a parameter, the principle of conservativeness must be applied (as described in Section 2.3 of the SOCIALCARBON Standard).

Box 1: Approaches to demonstrate historical land management.

Sources of information for all un-defined activity/management related model input variables (see Table 5 and Table 6) and parameters $FFC_{bsl,j,i,y}$, $P_{bsl,l,i,y}$, $Days_{bsl,l,i,y}$, $M_{bsl,SF,i,y}$, $M_{bsl,OF,i,y}$ and $MB_{g,bsl,i,y}$, relevant to the baseline, will follow requirements detailed below. All qualitative information on land management practices will be determined via consultation with, and substantiated with a signed attestation from, the farmer or landowner of the sample field during that period. Where the farmer or landowner is not able to provide qualitative information (e.g., a sample field is newly leased), the project proponent may follow the guidance for using the sources of quantitative information listed below. The source of quantitative information on land management practices, and any additional quantitative inputs where required by the model selected (Quantification Approach 1 and 3) must be chosen with priority from higher to lower preference, as available, as follows, applying the principle of conservatism in all cases:

1. Historical management records supported by one or more forms of documented evidence pertaining to the selected sample field and period t = -1 to t = -3 (e.g., management logs, receipts or invoices, farm equipment specifications, logs or files containing machine and/or sensor data), or remote sensing (e.g., satellite imagery, manned aerial vehicle footage, drone imagery) , where requisite information on agricultural management practices can be reliably determined with these methods (e.g., tillage status, crop type, irrigation).

2. Historical management plans supported by one or more forms of documented evidence pertaining to the selected sample field and period t = -1 to t = -3 (e.g., management plan, recommendations in writing solicited by the farmer or landowner from an agronomist). Where more than one value is documented in historical management plans (e.g., where a range of application rates are prescribed in written recommendations), the principle of conservatism will be applied, the value that results in the lowest expected emissions (or highest rate of stock change) in the baseline scenario must be selected.

3. Determined via consultation and substantiated with a signed attestation from the farmer or landowner of the sample field during that period, so long as the attested value does not deviate significantly from other evidence-supported values for similar fields (e.g., fertilizer data from adjacent fields with the same crop, adjacent years of the same field, government data of application rates in that area, or statement from a local extension agent regarding local application rates). The determination of the sufficiency of data is subject to the discretion of the VVB. In circumstances where this requirement cannot be met, option 4 must be followed.

4. Regional (sub-national) average values derived from agricultural census data or other sources from within the 20-year period preceding the project start date or the 10 most recent iterations of the dataset, whichever is more recent, referencing the relevant crop or ownership class where estimates have been disaggregated by those attributes, and substantiated with a signed attestation from the farmer or landowner of the sample field during that period. Examples include the US Department of Agriculture (USDA) National Agricultural Statistics Service Quick Stats database and USDA Agricultural Resource Management Survey.

9.1 Data and Parameters Available at Validation

Data / Parameter	AR
Data unit	Percent
Description	Weighted average adoption rate.
Equations	1
Source of data	Calculated for the project across the group or all activity instances
Value applied	Must be less than or equal to 20%
Justification of choice of data or description of measurement methods and procedures applied	See section 7
Purpose of Data	Common practice assessment
Comments	None

Data / Parameter	EA_{an}
Data unit	Percent
Description	Adoption rate of the n largest most common proposed project activity in the region
Equations	1
Source of data	Publicly available information contained in agricultural census or other government (e.g., survey) data, peer-reviewed scientific literature, independent research data, or reports/assessments compiled by industry associations. If all of the above sources are unavailable, signed and date attestation statement from a qualified independent local expert.
Value applied	Conditional on data source
Justification of choice of data or description of	See source of data above and Section 7

measurement methods and procedures applied	
Purpose of Data	Common practice assessment
Comments	None

Data / Parameter	$Area_{an}$
Data unit	Hectares or acres
Description	Area of proposed project-level adoption of each activity
Equations	Equation 1
Source of data	Farm records and project activity commitments
Value applied	Proposed project-level adoption of $\text{Activity}_{\text{an}}$
Justification of choice of data or description of measurement methods and procedures applied	See Section 7
Purpose of Data	Common practice assessment
Comments	None

Data / Parameter	A_0
Data unit	Unit area
Description	Total area of the project
Equations	Equations 63, 64, 65, 66
Source of data	Measured in project area
Value applied	The project area is measured prior to validation
Justification of choice of data or description of	Delineation of the project area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), or other appropriate data. Any imagery or GIS datasets

measurement methods and procedures applied	used must be geo-registered referencing corner points, clear landmarks or other intersection points.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{CO2,j}$
Data unit	tCO2e/litre
Description	Emission factor for the type of fossil fuel, j (gasoline or diesel) combusted
Equations	Equations 5
Source of data	Volume 2 Chapter 3 Table 3.3.1 (IPCC, 2019)
Value applied	For gasoline EF_{CO2}=0.002810 t CO2e per liter. For diesel EF_{CO2}=0.002886 t CO2e per liter
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	Assumes 4-stroke gasoline engine for gasoline combustion and default values for energy content of 47.1 GJ/t and 45.66 GJ/t for gasoline and diesel respectively (IEA, 2004).

Data / Parameter	$FFC_{bsl,j,i,y}$
Data unit	Litres
Description	Consumption of fossil fuel type j (gasoline or diesel) for sample unit i in year y.
Equations	Equations 5
Source of data	See Box 1
Value applied	See Box 1

Justification of choice of data or description of measurement methods and procedures applied	Fossil fuel consumption can be monitored, or the amount of fossil fuel combusted can be estimated using fuel efficiency (for example l/100 km, l/t-km, l/hour) of the vehicle and the appropriate unit of use for the selected fuel efficiency (for example km driven if efficiency is given in l/100 km).
Purpose of Data	Calculation of baseline
Comments	Peer-reviewed published data may be used to determine fuel efficiency. For example, fuel efficiency factors may be obtained from the (IPCC, 2019), Volume 2 Chapter 3

Data / Parameter	GWP_{CH4}
Data unit	tCO2e/tCH4
Description	Global warming potential for CH_4
Equations	Equations 6
Source of data	IPCC Fifth Assessment Report (IPCC, 2013)
Value applied	28
Justification of choice of data or description of measurement methods and procedures applied	See source of data above. SOCIALCARBON Standard v6.0 requires that CH_4 must be converted using the 100-year global warming potential derived from the IPCC Fifth Assessment Report for GHG emission reductions occurring on or after 1 January 2021.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{ent,l}$
Data unit	kg CH4/(head * year)
Description	Enteric emission factor for livestock type l
Equations	Equation 6
Source of data	Where no alternative information source is available that is applicable to the project conditions, project proponents may derive emission factors for each category of livestock estimated based on the gross

	energy intake and methane conversion factor for the category by following the guidance under “Tier 2 Approach for Methane Emissions from Enteric Fermentation” in Section 10.3.2, Chapter 10, Volume 4 of IPCC (2019). Where project proponents are able to justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a enteric fermentation emission factors from Tables 10.10 or 10.11, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Value applied	The emission factor is selected based on livestock type
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{CH4,md,l}$
Data unit	g CH4/(kg volatile solids)
Description	Emission factor for methane emissions from manure deposition for livestock type l
Equations	Equation 7
Source of data	Peer-reviewed published data may be used. For example, suitable values may be selected from Volume 4 Chapter 10 Table 10.10 and Table 10.11 (IPCC, 2019)
Value applied	The emission factor is determined based on livestock type. Excluding livestock types listed in Table 10.15 in Chapter 10, Volume 4 (IPCC, 2019), a value of 0.6 is applied for all animals in both low and high productivity pasture, range, and paddock systems per Table 10.14 of the same chapter.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$VS_{rate,l}$
Data unit	kg volatile solids/(1000 kg animal mass * day)
Description	Default volatile solids excretion rate for livestock type, l
Equations	Equations 7, 8
Source of data	Peer-reviewed published data may be used. For example, suitable values may be selected from Volume 4, Chapter 10 Table 10.13a (IPCC, 2019)
Value applied	The volatile solids excretion rate is determined based on livestock type. Where agricultural systems are differentiated into low and high productivity systems in Table 10.13a in Chapter 10, Volume 4 (IPCC, 2019), the mean value is selected.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	CF_c
Data unit	Proportion of pre-fire fuel biomass consumed
Description	Combustion factor for agricultural residue type c
Equations	Equations 9, 26
Source of data	2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 2 Table 2.6 Volume 4, Chapter 2, Table 2.6 (IPCC, 2019)
Value applied	The combustion factor is selected based on the agricultural residue type burned
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.

Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{c,CH4}$
Data unit	g CH4/kg dry matter burnt
Description	Methane emission factor for the burning of agricultural residue type c
Equations	Equation 9
Source of data	Volume 4, Chapter 2, Table 2.5 (IPCC, 2019)
Value applied	The emission factor is selected based on the agricultural residue type burned
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	GWP_{N2O}
Data unit	t CO2e / t N2O
Description	Global warming potential for N_2O
Equations	Equations 14, 18
Source of data	IPCC Fifth Assessment Report (IPCC, 2013)
Value applied	265
Justification of choice of data or description of measurement methods and procedures applied	See source of data above. SOCIALCARBON Standard v6.0, requires that N_2O must be converted using the 100-year global warming potential derived from the IPCC Fifth Assessment Report for GHG emission reductions occurring on or after 1 January 2021.

Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{Ndirect}$
Data unit	t N2O-N/t N applied
Description	Emission factor for direct nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments and crop residues
Equations	Equations 12, 18
Source of data	Volume 4 Chapter 11 Table 11.1 (IPCC, 2019)
Value applied	A value of 0.01 is applied for N additions from synthetic fertilizers, organic amendments and crop residues, and N mineralized from mineral soil as a result of loss of SOC. Disaggregated values may be used as follow: • A value of 0.016 is applied for inputs of synthetic fertilizer and fertilizer mixtures that include both synthetic and organic forms of N in wet climates • A value of 0.006 is applied for other N input as organic amendments, animal manures, N in crop residues and mineraliszed N from SOC decomposition in wet climates • A value of 0.005 is applied to all N inputs in dry climates A value of 0.004 is applied for manure from cattle (dairy, nondairy and buffalo), poultry and pigs. Disaggregated values may be used as follow: • A value of 0.006 is applied for wet climates • A value of 0.002 is applied for dry climates. A value of 0.003 is applied for manure from sheep and ‘’other animals’’. When specific emission factors are available, a Tier 2 approach may be applied following the guidance in Chapter 11 Section 11.2.2.1 - Choice of Method and the good practice guidance in Chapter 2 Section 2.2.4 - Emission factors and direct measurement of emissions (IPCC, 2019). depending on, e.g., SOC content, soil texture, drainage, soil pH, N application rate per fertilizer type; fertilizer type,

	liquid or solid form of organic fertilizer; irrigation and type of crop with differences between legumes, non-leguminous arable crops, and grass.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above. SOCIALCARBON Standard v6.0, requires that N_2O must be converted using the 100-year global warming potential derived from the IPCC Fifth Assessment Report for GHG emission reductions occurring on or after 1 January 2021.
Purpose of Data	Calculation of baseline and project emissions
Comments	Emission factor applicable to N additions from mineral fertilizers, organic amendments and crop residues, and N mineralized from mineral soil as result of loss of soil carbon. Wet climates occur in temperate and boreal zones where the ratio of annual precipitation: potential evapotranspiration > 1, and tropical zones where annual precipitation > 1000 mm. Dry climates occur in temperate and boreal zones where the ratio of annual precipitation: potential evapotranspiration < 1, and tropical zones where annual precipitation < 1000 mm. 'Other animals' include goats, horses, mules, donkeys, camels, reindeer, and camelids.

Data / Parameter	$FRAC_{GASF}$
Data unit	Dimensionless
Description	Fraction of all synthetic N added to soils that volatilizes as NH_3 and NO_x
Equations	Equation 16
Source of data	Volume 4, Chapter 11, Table 11.3 (IPCC, 2019)
Value applied	0.11
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$FRAC_{GASM}$
Data unit	Dimensionless
Description	Fraction of all organic N added to soils and N in manure and urine deposited on soils that volatilizes as NH_3 and NO_x
Equations	Equations 16, 24,
Source of data	Volume 4, Chapter 11, Table 11.3 (IPCC, 2019)
Value applied	0.21
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	EF_{Nvolat}
Data unit	t N_2O-N /(t NH_3-N + NO_x-N volatilized)
Description	Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces
Equations	Equation 16, 24
Source of data	Volume 4, Chapter 11, Table 11.3 (IPCC, 2019)
Value applied	0.01
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$FRAC_{LEACH}$
Data unit	Dimensionless
Description	Fraction of N added (synthetic or organic) to soils and N in manure and urine deposited on soils that is lost through leaching and runoff, in regions where leaching and runoff occurs
Equations	Equations 17, 25
Source of data	Volume 4, Chapter 11, Table 11.3 (IPCC, 2019)
Value applied	For wet climates or in dry climate regions where irrigation (other than drip irrigation) is used, a value of 0.24 is applied. For dry climates, a value of zero is applied.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	Wet climates occur in temperate and boreal zones where the ratio of annual precipitation: potential evapotranspiration > 1, and tropical zones where annual precipitation > 1000 mm. Dry climates occur in temperate and boreal zones where the ratio of annual precipitation: potential evapotranspiration < 1, and tropical zones where annual precipitation < 1000 mm.

Data / Parameter	EF_{Nleach}
Data unit	t N_2O-N / t N leached and runoff
Description	Emission factor for nitrous oxide emissions from leaching and runoff
Equations	Equations 17, 25
Source of data	Volume 4, Chapter 11, Table 11.3 (IPCC, 2019)
Value applied	0.011
Justification of choice of data or description of	See source of data above.

measurement methods and procedures applied	
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{N2O,md,l}$
Data unit	kg N_2O-N/kg N input
Description	Emission factor for nitrous oxide from manure and urine deposited on soils by livestock type l
Equations	Equation 21
Source of data	Volume 4, Chapter 11, Table 11.1 (IPCC, 2019)
Value applied	The emission factor for nitrous oxide from manure and urine deposited on soils is determined based on livestock type. For cattle, poultry, and pigs $EF_{N2O,md,l}$ = 0.004 kg N_2O-N/kg N input. For sheep and other animals $EF_{N2O,md,l}$=0.003 kg N_2O-N/kg N input.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	Nex_l
Data unit	kg N deposited/(t livestock mass * day)
Description	Average annual Nitrogen excretion per head of livestock type l
Equations	Equation 22
Source of data	Peer-reviewed published data may be used. For example, suitable values may be selected from Volume 4, Chapter 10, Table 10.19 (IPCC, 2019).

Value applied	The nitrogen excretion rate is determined based on livestock type. Where agricultural systems are differentiated into low and high productivity systems in Table 10.19 in Chapter 10, Volume 4, (IPCC, 2019), the mean value is selected. Typical animal mass values may be sourced from Annex 10A.1, Table 10A.5.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$MS_{bsl,l,i,y}$
Data unit	Fraction of N deposited
Description	Fraction of nitrogen excretion of livestock type l that is deposited on the project area
Equations	Equation 22
Source of data	Data may be sourced according to the guidance in Box 1
Value applied	The fraction of nitrogen deposited on the project area is determined based on the amount of time spent grazing on the project area during year y for each livestock type. In the absence of data available according to Box 1 (or to conservatively reduce the effort of project development), a value of 1 may be applied with no additional support. This would conservatively assume that the livestock deposited 100% of their excreted N on the project area for the entirety of year y.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$N_{content,g}$
Data unit	t N/t dm
Description	Fraction of N in dry matter for N-fixing species g
Equations	Equation 19
Source of data	Volume 4, Chapter 11, Table 11.1A (IPCC, 2019)
Value applied	The fraction of N in dry matter is determined based on the N-fixing species type.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{c,N2O}$
Data unit	g N2O/kg dry matter burnt
Description	Nitrous oxide emission factor for the burning of agricultural residue type c
Equations	Equations 26
Source of data	Volume 4, Chapter 2, Table 2.5 (IPCC, 2019)
Value applied	The emission factor is selected based on the agricultural residue type.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$P_{bsl,l,i,y}$
Data unit	Head
Description	Population of grazing livestock in the baseline scenario of type *l* in sample unit *i* in year y
Equations	Equation 6
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$Days_{bsl,l,i,y}$
Data unit	Days
Description	Average grazing days per head in the baseline scenario inside sample unit *i* for each livestock type in year *y*
Equations	Equations 6, 7
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$MB_{bsl,c,i,y}$
Data unit	Kilograms
Description	Mass of agricultural residues of type *c* burned in the baseline scenario for sample unit *i* in year *y*
Equations	Equations 9, 26
Source of data	Peer-reviewed published data may be used to estimate the aboveground biomass prior to burning.
Value applied	See source of data
Justification of choice of data or description of measurement methods and procedures applied	It is assumed that 100% of aboveground biomass is burned in both the baseline and with project cases.
Purpose of Data	Calculation of baseline emissions
Comments	Mass of residues burned is a function of the amount of aboveground biomass, the removal of aboveground biomass, and whether or not remaining residues are burned.

Data / Parameter	$MB_{bsl,SF,i,y}$
Data unit	t fertilizer
Description	Mass of baseline N containing synthetic fertilizer applied for sample unit *i* in year *y*
Equations	Equation 13
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$NC_{bsl,SF,i,y}$
Data unit	t N/t fertilizer
Description	N content of baseline synthetic fertilizer applied
Equations	Equation 13
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	N content is determined following fertilizer manufacturer's specifications
Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$M_{bsl,OF,i,y}$
Data unit	t fertilizer
Description	Mass of baseline N containing organic fertilizer applied for sample unit *i* in year *y*
Equations	Equation 14
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	N content is determined following fertilizer manufacturer's specifications
Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$NC_{bsl,OF,i,y}$
Data unit	t N/t fertilizer
Description	N content of baseline organic fertilizer applied
Equations	Equation 14
Source of data	Peer-reviewed published data may be used. For example, default manure N contents may be selected from (Edmonds et al., 2003) cited in (US EPA, 2011) or other regionally appropriate sources such as the European Environment Agency.
Value applied	See source of data
Justification of choice of data or description of measurement methods and procedures applied	See source of data
Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$MB_{g,bsl,i,y}$
Data unit	t dm
Description	Annual dry matter, including aboveground and below ground, of N-fixing species g returned to soils for sample unit *i* at time *y*
Equations	Equation 19
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Calculation of baseline emissions

Comments	Mass of residues burned is a function of the amount of aboveground biomass, the removal of aboveground biomass, and whether or not remaining residues are burned.

Data / Parameter	$P_{bsl,p}$
Data unit	Productivity (e.g., kg) per hectare or acre
Description	Average productivity for product *p* during the historical baseline period
Equations	Equations 40, 41
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Determination of baseline productivity for future market leakage analysis
Comments	None

Data / Parameter	$RP_{bsl,p}$
Data unit	Productivity (e.g., kg) per hectare or acre
Description	Average regional productivity for product *p* during the same years as the historical baseline period.
Equations	Equation 41
Source of data	Secondary evidence sources of regional productivity (e.g., peer-reviewed science, industry associations, international databases, government databases)
Value applied	Conditional on data source
Justification of choice of data or description of	See Box 1

measurement methods and procedures applied	
Purpose of Data	Determination of baseline productivity ratio for future market leakage analysis
Comments	None

Data / Parameter	$C_{tree,y}$
Data unit	tCO2e
Description	Areal average baseline carbon stock in tree biomass in the project area.
Equations	Equation 29
Source of data	Data can be collected either through direct measurement using remote sensing.
Value applied	NA
Justification of choice of data or description of measurement methods and procedures applied	NA
Purpose of Data	Calculation of baseline carbon stocks.
Comments	Direct measurement should follow the procedures outlined in the CDM tools *CDM A/R Tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* and *Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.* Project Proponents are permitted to utilise emerging technology (e.g. remote sensing) with known uncertainty to measure tree carbon stocks. Models must at a minimum: • be publicly available from a reputable and recognized source (e.g., the model developer's website, IPCC, or government agency); and • have been appropriately reviewed and tested under similar ecosystemic conditions by a recognized, competent organization, or an appropriate peer review group; and

	• have comprehensive and appropriate requirements for estimating uncertainty in keeping with IPCC or other appropriate guidance, and the model shall be calibrated by parameters such as geographic location and local climate data; and • apply conservative factors to discount for model uncertainty and shall use conservative assumptions and parameters that are likely to underestimate, rather than overestimate, the GHG emission reductions or removals. All parameters, data sources and assumptions applied by the emerging technology must be documented in the Project Description Document. The approach applied to measuring the baseline carbon stock must be applied do the duration of the project crediting period.

Data / Parameter	$C_{shrub,y}$
Data unit	tCO2e
Description	Areal average baseline carbon stock in shrub biomass in the project area.
Equations	Equation 30
Source of data	Data can be collected either through direct measurement using remote sensing.
Value applied	NA
Justification of choice of data or description of measurement methods and procedures applied	NA
Purpose of Data	Calculation of baseline carbon stocks.
Comments	Direct measurement should follow the procedures outlined in the CDM tools *CDM A/R Tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* and *Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.*

	Project Proponents are permitted to utilise emerging technology (e.g. remote sensing) with known uncertainty to measure tree carbon stocks. Models must at a minimum: • be publicly available from a reputable and recognized source (e.g., the model developer's website, IPCC, or government agency); and • have been appropriately reviewed and tested under similar ecosystemic conditions by a recognized, competent organization, or an appropriate peer review group; and • have comprehensive and appropriate requirements for estimating uncertainty in keeping with IPCC or other appropriate guidance, and the model shall be calibrated by parameters such as geographic location and local climate data; and • apply conservative factors to discount for model uncertainty and shall use conservative assumptions and parameters that are likely to underestimate, rather than overestimate, the GHG emission reductions or removals. All parameters, data sources and assumptions applied by the emerging technology must be documented in the Project Description Document. The approach applied to measuring the baseline carbon stock must be applied do the duration of the project crediting period.

Data / Parameter:	$f(SOC_{bsl,i,y})$
Data unit:	tCO2e/unit area
Description:	Modelled soil organic carbon stocks pool in the baseline scenario for sample unit i in year y
Equations	Equations 3
Source of data:	Modelled in the project area. **Note:** regional data published by government bodies or peer-reviewed papers may be used for the baseline carbon stocks if Quantification Approach 3 is applied. (This approach is focused on measuring carbon fluxes)
Description of measurement methods and procedures to be applied:	Modelled soil organic carbon stocks in the baseline scenario are determined according to the equation: $SOC_{bsl,i,y} = f_{SOC}(Var\ A_{bsl,i,y}, Var\ B_{bsl,i,y}, \dots)$

	Where: $SOC_{bsl,i,y}$ = Modelled soil organic carbon stocks pool in the baseline scenario for sample unit *i* at time y (t CO2e/unit area) f_{SOC} = Model predicting carbon dioxide emissions from the soil organic carbon pool (t CO2e/unit area) $Var\ A_{bsl,i,y}$ = Value of model input variable A in the baseline scenario for sample unit i at time y (units unspecified) $Var\ B_{bsl,i,y}$ = Value of model input variable B in the baseline scenario for sample unit i at time y (units unspecified) See Box 1 for sources of data and description of measurement methods and procedures to be applied to obtain values for model input variables.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QCs available from published handbooks, such as those published by FAO and available on the FAO Soils Portal (http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/), or from the IPCC GPG LULUCF 2003 is recommended.
Purpose of data:	Calculation of baseline emissions
Calculation method:	NA
Comments:	The soil organic carbon stocks at time y=0 are calculated based on directly measured soil organic carbon content and bulk density at y=0 or (back-) modeled to y =0 from measurements via conventional analytical laboratory methods, e.g., dry combustion, collected performed within +/-5 years of y=0, or determined for y=0 via emerging technologies (e.g., remote sensing, INS, LIBS, MIR and Vis-NIR) with known uncertainty following the criteria in Appendix 3: guidance on potential emerging technologies to measure SOC stocks and Appendix 5: Considerations for Approaching Uncertainty in

	Remote Sensing Measurements: Guidance on potential emerging technologies to measure SOC stocks, and must be used in both the baseline and project scenario for the length of the project.

Data / Parameter:	$SOC_{bsl,i,y}$
Data unit:	tCO2e/unit area
Description:	Areal-average soil organic carbon stocks in the baseline scenario for sample unit i in year y
Equations	Equations 27, 28
Source of data:	Modelled in the project area or measured at validation.
Description of measurement methods and procedures to be applied:	See $f\left(SOC_{bsl,i,y}\right)$ above for modelled soil organic carbon stocks. Measured soil organic carbon must be determined from samples collected from sample plots located within each sample site. All organic material (e.g., living plants, crop residue) must be cleared from the soil surface prior to soil sampling. Soil must be sampled to a minimum depth of 30 cm. Soil organic carbon stocks must be estimated from measurements of both soil organic carbon content and bulk density taken at the same time, at the project start and re-measured every 5 years or less. Geographic locations of intended sampling points must be established prior to sampling. The location of both the intended sampling point and the actual sampling point must be recorded. If multiple cores are composited to create a single sample, these cores must all be from the same depth and be fully homogenized prior to subsampling. Soils must be shipped within 5 days of collection and should be kept cool until shipping. Acknowledging the wide range of valid monitoring approaches, and that relative efficiency and robustness are circumstance-specific, sampling, measurement and estimation procedures for measuring are not specified in the methodology and may be selected by project proponents based on capacity and appropriateness. Stratification may be employed to improve precision but is not required. Estimates generated must: • Be demonstrated to be unbiased and derived from representative sampling

	- Accuracy of measurements and procedures is ensured through employment of quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in the monitoring plan) Soil sampling should follow established best practices, such as those found in: (Cline, 1944; Petersen and Calvin, 1986; Gruijter et al., 2006; Soil Science Division Staff, 2017; FAO, 2019; Smith et al., 2020). When measuring SOC via conventional analytical laboratory methods, the use of dry combustion is recommended over other techniques. Determination of percent soil organic carbon should follow established laboratory procedures, such as those found in: (Nelson and Sommers, 1982; ISO, 1995; Schumacher, 2002). Standardization of soil measurement methods is a globally recognized need (for example: ISRIC World Soil Information Service (WoSIS)- see Ribeiro et al. (2018)). Measurement procedures for soil organic carbon and bulk density should be thoroughly described, including all sample handling, preparation for analysis, and analysis techniques.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See $f\left(SOC_{bsl,i,y}\right)$ above if modelled.
Purpose of data:	Calculation of baseline emissions
Calculation method:	NA
Comments:	The soil organic carbon stocks at time t=0 are calculated based on directly measured soil organic carbon content and bulk density at t=0 or (back-) modeled to t =0 from measurements collected within +/-5 years of t =0, or determined for t=0 via emerging technologies (e.g., proximal sensing) with known uncertainty, and must be used in both the baseline and with- project scenario for the length of the project. Note that bulk density measurements are not necessarily required to determine SOC stock changes on an ESM basis. Soil organic carbon stocks in the baseline scenario for sample unit i must be reported every 5 years or less.

9.2 Data and Parameters Monitored

Data / Parameter:	AR
Data unit:	Percent
Description:	Weighted average adoption rate.
Equations	1
Source of data:	Calculated for the project across the group or all activity instances
Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	Whenever a new instance is added
QA/QC procedures to be applied:	See Section 7
Purpose of data:	Common practice assessment
Calculation method:	See Section 7
Comments:	None

Data / Parameter:	EA_{an}
Data unit:	Percent
Description:	Adoption rate of the n largest most common proposed project activity in the region
Equations	1
Source of data:	Publicly available information contained in agricultural census or other government (e.g., survey) data, peer-reviewed scientific literature, independent research data, or reports/assessments compiled by industry associations. If all of the above sources are unavailable, signed and date attestation statement from a qualified independent local expert.

Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	Whenever a new instance is added
QA/QC procedures to be applied:	See Section 7
Purpose of data:	Common practice assessment
Calculation method:	NA
Comments:	None

Data / Parameter:	$Area_{an}$
Data unit:	Unit area (hectares or acres)
Description:	Project Area
Equations	Equation 1
Source of data:	Farm records and project activity commitments
Description of measurement methods and procedures to be applied:	The area is estimated prior to verification.
Frequency of monitoring/recording:	Whenever a new instance is added.
QA/QC procedures to be applied:	Delineation of the sample unit area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), or other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, clear landmarks or other intersection points.
Purpose of data:	Common practice assessment
Calculation method:	NA

Comments:	None

Data / Parameter:	A_i
Data unit:	Unit area
Description:	Area of sample unit *i*
Equations	Equations 4, 14, 18, 49, 57, 58, 59
Source of data:	Determined in project area
Description of measurement methods and procedures to be applied:	The sample unit area is measured prior to verification
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Delineation of the sample unit area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), or other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, clear landmarks or other intersection points.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	i
Data unit:	Dimensionless
Description:	Sample unit; defined area that is selected for measurement and monitoring, such as a field or stratum; see also definition in section 3.
Equations	Equations 2, 4, 11, 19,
Source of data:	Determined in project area

Description of measurement methods and procedures to be applied:	The sample unit is measured prior to verification
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Delineation of the sample unit area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), or other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, clear landmarks or other intersection points.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	j
Data unit:	Dimensionless
Description:	Type of fossil fuel combusted
Equations	Equation 4
Source of data:	Determined in sample unit i
Description of measurement methods and procedures to be applied:	See Box 1. Fossil fuel type is determined prior to verification.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	NA

Comments:	None

Data / Parameter:	l
Data unit:	Dimensionless
Description:	Type of livestock
Equations	Equation 6
Source of data:	Determined in sample unit i
Description of measurement methods and procedures to be applied:	See Box 1. Livestock type is determined prior to verification.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	g
Data unit:	Dimensionless
Description:	Type of N-Fixing species
Equations	Equation 19
Source of data:	Determined in sample unit i
Description of measurement methods	See Box 1. N-Fixing species type is determined prior to verification.

and procedures to be applied:	
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	c
Data unit:	Dimensionless
Description:	Type of agricultural residue
Equations	Equations 9, 26
Source of data:	Determined in sample unit i
Description of measurement methods and procedures to be applied:	See Box 1. Agricultural residue type is determined prior to verification.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	SF

Data unit:	Dimensionless
Description:	Type of synthetic N fertilizer
Equations	Equations 14
Source of data:	Determined in sample unit i
Description of measurement methods and procedures to be applied:	See Box 1. Synthetic fertilizer type is determined prior to verification.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	OF
Data unit:	Dimensionless
Description:	Type of Organic N fertilizer
Equations	Equations 14
Source of data:	Determined in sample unit i
Description of measurement methods and procedures to be applied:	See Box 1. Organic fertilizer type is determined prior to verification.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years

QA/QC procedures to be applied:	See Box 1.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	$SOC_{wp,i,y}$
Data unit:	t CO2e/unit area
Description:	Areal-average soil organic carbon stocks in the project scenario for sample unit i in year y
Equations	Equation 28
Source of data:	Modelled or measured in the project area
Description of measurement methods and procedures to be applied:	Modelled soil organic carbon stocks in the project scenario are determined according to the equation: $fSOC_{wp,i,y} = f_{SOC}(Var\ A_{wp,i,y}, Var\ B_{wp,i,y}, \ldots)$ Where: $fSOC_{wp,i,y}$ = Modelled soil organic carbon stocks pool in the baseline scenario for sample unit *i* at time y (t CO2e/unit area) f_{SOC} = Model predicting carbon dioxide emissions from the soil organic carbon pool (t CO2e/unit area) $Var\ A_{wp,i,y}$ = Value of model input variable A in the project scenario for sample unit i at time y (units unspecified) $Var\ B_{wp,i,y}$ = Value of model input variable B in the project scenario for sample unit i at time y (units unspecified)

See Box 1 for sources of data and description of measurement methods and procedures to be applied to obtain values for model input variables.

Measured soil organic carbon must be determined from samples collected from sample plots located within each sample unit. All organic material (e.g., living plants, crop residue) must be cleared from the soil surface prior to soil sampling. Soil must be sampled to a minimum depth of 30 cm, ideally as contiguous cores divided into many short increments (e.g., 5 or 10 cm in length) to enable following the equivalent soil mass (ESM) approach (Ellert and Bettany, 1995). To eliminate the need for extrapolation outside of the measured range, soils should be sampled one increment deeper than the minimum 30 cm required. Soil organic carbon stocks must be estimated from measurements of both soil organic carbon content and bulk density taken at the same time, at the project start and remeasured every 5 years or less. Note that bulk density measurements are not necessarily required to determine SOC stock changes on an ESM basis.

If organic amendments are applied, projects should delay sampling or re-sampling to the latest time possible after the previous application and the shortest time possible before the next one. Sampling and re-sampling campaigns after several years should be conducted during the same season.

Bulk density as soil mass per volume of sampling cores shall not include the mass of soil >2mm, i.e. gravel/stones and plant material. Beem-Miller, et al. (2016) provides a useful approach to ensuring high-quality sampling in rocky agricultural soils. Analysis of soil carbon content should be performed on the same samples for which dry soil mass is measured.

Geographic locations of intended sampling points must be established prior to sampling. The location of both the intended sampling point and the actual sampling point must be recorded.

If multiple cores are composited to create a single sample, these cores must all be from the same depth and be fully homogenized prior to subsampling.

Soil samples must be shipped to the laboratory within 5 days of collection and should be kept cool until shipping. Sample preparation should follow standards, such as ISO 11464.

Acknowledging the wide range of valid monitoring approaches, and that relative efficiency and robustness are circumstance-specific,

	sampling, measurement and estimation procedures for measuring are not specified in the methodology and may be selected by project proponents based on capacity and appropriateness. Stratification may be employed to improve precision but is not required. Estimates generated must: • Be demonstrated to be unbiased and derived from representative sampling • Accuracy of measurements and procedures is ensured through employment of quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in the monitoring plan) Soil sampling should follow established best practices, such as those found in (Cline, 1944; Petersen and Calvin, 1986; Gruijter et al., 2006; Soil Science Division Staff, 2017; FAO, 2019; Smith et al., 2020). When measuring SOC via conventional analytical laboratory methods, the use of dry combustion is recommended over other techniques. Determination of percent soil organic carbon should follow established laboratory procedures, such as those found in: (Nelson and Sommers, 1982; ISO, 1995; Schumacher, 2002). Standardization of soil measurement methods is a globally recognized need (for example: ISRIC World Soil Information Service (WoSIS) (Ribeiro, Batjes and van Oostrum, 2018)). Measurement procedures for soil organic carbon and bulk density should be thoroughly described, including all sample handling, preparation for analysis, and analysis techniques.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QCs available from published handbooks, such as those published by FAO and available on the FAO Soils Portal (http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/), or from the IPCC GPG LULUCF 2003 is recommended.
Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	The soil organic carbon stocks at time y=0 are calculated based on directly measured soil organic carbon content and bulk density at y=0 or (back) modeled to y =0 from measurements via conventional analytical laboratory methods, e.g., dry combustion, collected performed within +/-5 years of y=0, or determined for y=0 via emerging technologies (e.g., remote sensing, INS, LIBS, MIR and Vis-NIR) with

	known uncertainty following the criteria in Appendix 3: guidance on potential emerging technologies to measure SOC stocks and Appendix 5: Considerations for Approaching Uncertainty in Remote Sensing Measurements: Guidance on potential emerging technologies to measure SOC stocks, and must be used in both the baseline and project scenario for the length of the project. Note that bulk density measurements are not necessarily required to determine SOC stock changes on an ESM basis. Soil organic carbon stocks in the project scenario for sample unit *i* must be reported every 5 years or less. Where re-measurement of soil organic carbon stocks indicates lower stocks than previously estimated by modeling, procedures in the most current version of the *SOCIALCARBON Registration and Issuance Process* for loss or reversal events are followed, as appropriate.

Data / Parameter:	$SOC_{wp,i,y-1}$
Data unit:	t CO2e/unit area
Description:	Areal-average soil organic carbon stocks in the project scenario for sample unit i in year $y-1$
Equations	Equation 28
Source of data:	Modelled or measured in the project area.
Description of measurement methods and procedures to be applied:	See $SOC_{wp,i,y}$ above.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See $SOC_{wp,i,y}$ above.
Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	See $SOC_{wp,i,y}$ above.

Data / Parameter:	$M_{n,dl,SOC}$
Data unit:	g
Description:	Soil mass in one sample depth layer
Equations	Equation 2
Source of data:	Measured after soil sampling in the project area
Description of measurement methods and procedures to be applied:	See $SOC_{wp,i,y}$ above.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Soil sampling should follow established best practices, such as those found in Gruijter et al., 2006; Soil Science Division Staff, 2017; FAO, 2019; Smith et al., 2020. Soil mass shall not include the mass of soil >2mm, i.e. gravel/stones and plant material. Beem-Miller, et al. (2016) provides a useful approach to ensuring high-quality sampling in rocky agricultural soils.
Purpose of data:	Calculation of project emissions
Calculation method:	A detailed description of SOC stock calculations with multiple soil depth increments along with spreadsheets or R scripts to standardize and facilitate calculations are provided in Wendt and Hauser, 2013 and von Haden, Yang and DeLucia, 2020.
Comments:	None

Data / Parameter:	D
Data unit:	mm
Description:	Inside diameter of probe or auger
Equations	Equation 2
Source of data:	Measured as part of project monitoring
Description of measurement methods	NA

and procedures to be applied:	
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Soil sampling should follow established best practices, such as those found in Gruijter et al., 2006; Soil Science Division Staff, 2017; FAO, 2019; Smith et al., 2020.
Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	N
Data unit:	Unitless
Description:	Number of cores sampled
Equations	Equation 2
Source of data:	Measured in the project area
Description of measurement methods and procedures to be applied:	The number of samples taken is determined as part of the development of a sampling strategy (see section 9.3.1)
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QCs available from published handbooks, such as those published by FAO and available on the FAO Soils Portal (http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/), or from the IPCC GPG LULUCF 2003 is recommended.
Purpose of data:	Calculation of project emissions
Calculation method:	NA

Comments:	None

Data / Parameter:	$OC_{n,dl}$
Data unit:	g/kg
Description:	Organic carbon concentration in each sample
Equations	Equation 2
Source of data:	Measured in the project area
Description of measurement methods and procedures to be applied:	When measuring SOC content via conventional analytical laboratory methods, the use of dry combustion is recommended over other techniques. Emerging technologies (INS, LIBS, MIR and Vis-NIR) with known uncertainty may be applied to measure SOC concentration following the criteria in Appendix 3: guidance on potential emerging technologies to measure SOC stocks.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Determination of percent soil organic carbon should follow established laboratory standard operation procedures, such as those found in: (Nelson and Sommers, 1982; ISO, 1995; Schumacher, 2002).
Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	$\Delta C_{tree,,y}$
Data unit:	tCO2e/unit area
Description:	Change in carbon stocks in trees in the project scenario
Equations	Equations 29
Source of data:	Determined in project area

Description of measurement methods and procedures to be applied:	Method must be consistent with approach used to determine the baseline carbon stocks for trees. Direct measurement should follow the procedures outlined in the CDM tools *CDM A/R Tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* and *Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.* Project Proponents are permitted to utilise emerging technology (e.g. remote sensing) with known uncertainty to measure tree carbon stocks. Models must at a minimum: • be publicly available from a reputable and recognized source (e.g., the model developer's website, IPCC, or government agency); and • have been appropriately reviewed and tested under similar ecosystemic conditions by a recognized, competent organization, or an appropriate peer review group; and • have comprehensive and appropriate requirements for estimating uncertainty in keeping with IPCC or other appropriate guidance, and the model shall be calibrated by parameters such as geographic location and local climate data; and • apply conservative factors to discount for model uncertainty and shall use conservative assumptions and parameters that are likely to underestimate, rather than overestimate, the GHG emission reductions or removals. All parameters, data sources and assumptions applied by the emerging technology must be documented in the Monitoring report.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See description of measurement methods and procedures to be applied
Purpose of data:	Calculation of project carbon stocks
Calculation method:	See description of measurement methods and procedures to be applied
Comments:	None

Data / Parameter:	$\Delta C_{shrub,,y}$
Data unit:	tCO2e/unit area
Description:	Change in carbon stocks in shrub in the project scenario
Equations	Equations 30
Source of data:	Determined in project area
Description of measurement methods and procedures to be applied:	Method must be consistent with approach used to determine the baseline carbon stocks for shrub. Direct measurement should follow the procedures outlined in the CDM tools *CDM A/R Tools Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* and *Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.* Project Proponents are permitted to utilise emerging technology (e.g. remote sensing) with known uncertainty to measure shrub carbon stocks. Models must at a minimum: • be publicly available from a reputable and recognized source (e.g., the model developer's website, IPCC, or government agency); and • have been appropriately reviewed and tested under similar ecosystemic conditions by a recognized, competent organization, or an appropriate peer review group; and • have comprehensive and appropriate requirements for estimating uncertainty in keeping with IPCC or other appropriate guidance, and the model shall be calibrated by parameters such as geographic location and local climate data; and • apply conservative factors to discount for model uncertainty and shall use conservative assumptions and parameters that are likely to underestimate, rather than overestimate, the GHG emission reductions or removals. All parameters, data sources and assumptions applied by the emerging technology must be documented in the Monitoring report.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years

QA/QC procedures to be applied:	See description of measurement methods and procedures to be applied
Purpose of data:	Calculation of project carbon stocks
Calculation method:	See description of measurement methods and procedures to be applied
Comments:	None

Data / Parameter:	$FFC_{wp,j,i,y}$
Data unit:	Litres
Description:	Consumption of fossil fuel type j in the project for sample unit i in year y
Equations	Equation 5
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	Fossil fuel consumption can be monitored, or the amount of fossil fuel combusted can be estimated using fuel efficiency (for example l/100 km, l/t-km, l/hour) of the vehicle type and the appropriate unit of use for the selected fuel efficiency (for example km driven if efficiency is given in l/100 km).
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Guidance provided in IPCC, 2003 Chapter 5 or IPCC, 2000 Chapter 8 must be applied
Purpose of data:	Calculation of project emissions
Calculation method:	Fuel efficiency factors can be obtained from the Volume 2, Chapter 3 (IPCC, 2019)
Comments:	For all equations, the subscript *bsl* must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$P_{wp,l,i,y}$

Data unit:	Head
Description:	Population of grazing livestock in the project scenario of type l in sample unit i in year y
Equations	Equation 6
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	Record numbers of grazing livestock by type.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Information will be monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the sample unit. Any quantitative information (e.g., discrete or continuous numeric variables) on agricultural management practices must be supported by one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts or invoices, farm equipment specifications).
Purpose of data:	Calculation of project emissions
Calculation method:	Fuel efficiency factors can be obtained from the Volume 2, Chapter 3 (IPCC, 2019)
Comments:	For all equations, the subscript bsl must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$Days_{wp,l,i,y}$
Data unit:	Days
Description:	Average grazing days per head in the project scenario inside sample unit i for each livestock type l in year y
Equations	Equations 6, 7
Source of data:	See Box 1

Description of measurement methods and procedures to be applied:	Record numbers of grazing livestock by type.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Information will be monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the sample unit. Any quantitative information (e.g., discrete or continuous numeric variables) on agricultural management practices must be supported by one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts or invoices, farm equipment specifications).
Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	For all equations, the subscript *bsl* must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$MB_{wp,c,i,y}$
Data unit:	Kilograms
Description:	Mass of agricultural residues of type c burned in the project for sample unit i in year y
Equations	Equations 9, 26
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	Estimate the aboveground biomass of grassland before burning for at least three plots (1m*1m). The difference of the aboveground biomass is the aboveground biomass burnt
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Guidance provided in (IPCC, 2003) Chapter 5 or (IPCC, 2000) Chapter 8 must be applied.

Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	For all equations, the subscript *bsl* must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$M_{wp,SF,i,y}$
Data unit:	t Fertilizer
Description:	Mass of N containing synthetic fertilizer applied in the project for sample unit i in year y
Equations	Equation 13
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	See Box 1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Information will be monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the sample unit. Any quantitative information (e.g., discrete or continuous numeric variables) on agricultural management practices must be supported by one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts or invoices, farm equipment specifications).
Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	For all equations, the subscript bsl must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$M_{wp,OF,i,y}$

Data unit:	t Fertilizer
Description:	Mass of N containing organic fertilizer applied in the project for sample unit i in year y
Equations	Equation 14
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	See Box 1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Information will be monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the sample unit. Any quantitative information (e.g., discrete or continuous numeric variables) on agricultural management practices must be supported by one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts or invoices, farm equipment specifications).
Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	For all equations, the subscript bsl must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$W_{wp,l,i,y}$
Data unit:	Kg animal mass/head
Description:	Average weight in the project scenario of livestock type l for sample unit i in year y
Equations	Equation 8
Source of data:	Peer-reviewed published data or expert judgement may be used
Description of measurement methods	See source above

and procedures to be applied:	
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	The project proponent must justify why the values selected for these parameters results in emission reductions that are conservative
Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	For all equations, the subscript *bsl* must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$MB_{g,wp,i,y}$
Data unit:	t dm
Description:	Annual dry matter, including aboveground and below ground, of N-fixing species g returned to soils for sample unit i in year y
Equations	Equation 19
Source of data:	Aboveground and belowground dry matter in N-fixing species g returned to soil may be directly measured, or peer-reviewed published data may be used.
Description of measurement methods and procedures to be applied:	See source above
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	
Purpose of data:	Calculation of project emissions
Calculation method:	NA

Comments:	For all equations, the subscript *bsl* must be substituted by wp to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	LE_y
Data unit:	tCO2e
Description:	Leakage in year y;
Equations	Equation 39
Source of data:	NA
Description of measurement methods and procedures to be applied:	Leakage is calculated as per Section 8.3 of this document.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	
Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	$\mathrm{M}_{manure_{prj,l,y}}$
Data unit:	tonnes
Description:	Project manure applied as fertilizer on the project area from livestock type l in year y
Equations	Equation 45
Source of data:	See Box 1

Description of measurement methods and procedures to be applied:	See Box 1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Calculation of project emissions
Calculation method:	NA
Comments:	None

Data / Parameter:	$CC_{prj,l,y}$
Data unit:	Fraction
Description:	Carbon content of manure applied as fertilizer on the project area from livestock type l in year y
Equations	Equation 45
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	See Box 1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Calculation of project emissions from leakage
Calculation method:	NA
Comments:	None

Data / Parameter:	ΔP
Data unit:	Percent
Description:	Change in productivity
Equations	Equations 40, 41
Source of data:	Calculated (NA)
Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	Every 10 years
QA/QC procedures to be applied:	NA
Purpose of data:	Determination of change in crop/livestock productivity for leakage analysis
Calculation method:	See Section 8.3
Comments:	None

Data / Parameter:	$P_{wp,p}$
Data unit:	Productivity (e.g., kg) per hectare or acre
Description:	Average productivity for product p during the project period
Equations	Equations 40, 41
Source of data:	Farm productivity (e.g., yield) records
Description of measurement methods and procedures to be applied:	Measured using locally available technologies (e.g., mobile weighing devices, commercial scales, storage volume measurements, fixed scales, weigh scale tickets, etc.)

Frequency of monitoring/recording:	Each growing season
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Determination of project productivity for market leakage analysis
Calculation method:	Not applicable (measured)
Comments:	None

Data / Parameter:	p
Data unit:	Categorical variable
Description:	Crop/livestock product
Equations	Equation 41
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	Each growing season
QA/QC procedures to be applied:	NA
Purpose of data:	Identification of crop/livestock product for market leakage analysis
Calculation method:	NA
Comments:	None

Data / Parameter:	ΔPR
Data unit:	Percent

Description:	Change in productivity ratio
Equations	Equation 41
Source of data:	Calculated (not applicable)
Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	Every 10 years
QA/QC procedures to be applied:	NA
Purpose of data:	Determination of change in crop/livestock productivity for leakage analysis
Calculation method:	See Section 8.3
Comments:	None
Data / Parameter:	$RP_{wp,p}$
Data unit:	Unitless
Description:	Average regional productivity for product p during the same years as the project period
Equations	Equation 41
Source of data:	Regional productivity data from government (e.g., USDA Actual Production History data), industry, published, academic or international organization (e.g., FAO) sources.
Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	Every 10 years
QA/QC procedures to be applied:	NA

Purpose of data:	Determination of project productivity ratio for market leakage analysis
Calculation method:	NA
Comments:	None

Data / Parameter:	Buffer_y
Data unit:	tCO2e
Description:	Number of buffer credits to be deducted to compensated for non-permanence risk in year y
Equations	
Source of data:	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the latest version of the *SOCIALCARBON AFOLU Non-Permanence Risk Tool*
Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	Prior to each verification event.
QA/QC procedures to be applied:	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the latest version of the *SOCIALCARBON AFOLU Non-Permanence Risk Tool*
Purpose of data:	Calculation of project emissions
Calculation method:	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the latest version of the *SOCIALCARBON AFOLU Non-Permanence Risk Tool*
Comments:	None

Data / Parameter:	MDD
Data unit:	tCO2e / unit area

Description:	Minimum detectable difference of SOC stocks between two points in time
Equations	Equations 60, 61
Source of data:	Estimation of the smallest difference in SOC stock between two monitoring events that can be detected as statistically significant.
Description of measurement methods and procedures to be applied:	See section 9.3.1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See section 9.3.1 and further guidance in FAO, 2019
Purpose of data:	Development of sampling strategy for baseline setting or measurements for monitoring
Calculation method:	See section 9.3.1
Comments:	Calculation of the number of required samples to detect a minimum difference is optional for projects

Data / Parameter:	S
Data unit:	Dimensionless
Description:	Standard deviation of the difference in SOC stocks between y0 and y1
Equations	Equations 60, 61
Source of data:	Estimation of the smallest difference in SOC stock between two monitoring events that can be detected as statistically significant.
Description of measurement methods and procedures to be applied:	See section 9.3.1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years

QA/QC procedures to be applied:	See section 9.3.1 and further guidance in FAO, 2019
Purpose of data:	Development of sampling strategy for baseline setting or measurements for monitoring
Calculation method:	See section 9.3.1
Comments:	Calculation of the number of required samples to detect a minimum difference is optional for projects

Data / Parameter:	n
Data unit:	Dimensionless
Description:	Number of samples required to detect a minimum difference
Equations	Equations 60, 61
Source of data:	Estimation of the smallest difference in SOC stock between two monitoring events that can be detected as statistically significant.
Description of measurement methods and procedures to be applied:	See section 9.3.1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See section 9.3.1 and further guidance in FAO, 2019
Purpose of data:	Development of sampling strategy for baseline setting or measurements for monitoring
Calculation method:	See section 9.3.1
Comments:	Calculation of the number of required samples to detect a minimum difference is optional for projects

Data / Parameter:	v
Data unit:	Dimensionless

Description:	Degrees of freedom for the relevant t-distribution
Equations	Equations 60, 61
Source of data:	Estimation of the smallest difference in SOC stock between two monitoring events that can be detected as statistically significant.
Description of measurement methods and procedures to be applied:	See section 9.3.1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See section 9.3.1 and further guidance in FAO, 2019
Purpose of data:	Development of sampling strategy for baseline setting or measurements for monitoring
Calculation method:	See section 9.3.1
Comments:	Calculation of the number of required samples to detect a minimum difference is optional for projects

Data / Parameter:	t
Data unit:	Dimensionless
Description:	Values of the t-distribution given a certain power level (1-β) and α level (i.e., significance level)
Equations	Equations 60, 61
Source of data:	Estimation of the smallest difference in SOC stock between two monitoring events that can be detected as statistically significant.
Description of measurement methods and procedures to be applied:	See section 9.3.1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years

QA/QC procedures to be applied:	See section 9.3.1 and further guidance in FAO, 2019
Purpose of data:	Development of sampling strategy for baseline setting or measurements for monitoring
Calculation method:	See section 9.3.1
Comments:	Calculation of the number of required samples to detect a minimum difference is optional for projects

Data / Parameter:	$B_{Biomass,y}$
Data unit:	Tonnes
Description:	Quantity of biomass from outside the project that replaces biomass used for cooking/heating diverted to agricultural system in year y
Equations	Equation 43
Source of data:	For baseline scenario see Box 1. Ongoing monitoring should be conducted through direct measurement for sample unit i
Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years

Data / Parameter:	$fNRB$
Data unit:	Percent
Description:	Fraction of non-renewable biomass from outside the project in year y
Equations	Equation 43
Source of data:	IPCC defaults, national or regional studies
Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	NA
Purpose of data:	Determination of change in non-renewable fuel sourcing for leakage analysis
Calculation method:	NA
Comments:	None

Data / Parameter:	$NCV_{biomass}$
Data unit:	TJ/ tonne
Description:	Net calorific value of the non-renewable biomass from outside the project in year y.
Equations	Equation 43
Source of data:	For baseline scenario see Box 1. Ongoing monitoring should be conducted through direct measurement for sample unit i
Description of measurement methods	NA

and procedures to be applied:	
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	NA
Purpose of data:	IPCC defaults, National or regional studies
Calculation method:	NA
Comments:	None

Data / Parameter:	$NCV_{fossil\ fuel}$
Data unit:	TJ/ tonne
Description:	Net calorific value of the fossil fuel used to substitute biomass in the project in year y.
Equations	Equation 44
Source of data:	IPCC defaults, National or regional studies
Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	NA
Purpose of data:	Determination of change in non-renewable fuel sourcing for leakage analysis
Calculation method:	NA
Comments:	None

Data / Parameter:	$EF_{fossil\ fuel_y}$
Data unit:	tCO2e/ TJ
Description:	Emission factor of fossil fuel as substitute for non-renewable biomass in year y
Equations	Equation 44
Source of data:	Default value of 81.6 tCO2e/TJ I as per AMS I.E
Description of measurement methods and procedures to be applied:	NA
Frequency of monitoring/recording:	NA
QA/QC procedures to be applied:	NA
Purpose of data:	Determination of change in non-renewable fuel sourcing for leakage analysis
Calculation method:	NA
Comments:	None

9.3 Description of the Monitoring Plan

The methodology allows for a range of monitoring approaches. Monitored parameters are collected and recorded at the sample unit scale, and emissions are estimated independently for every sample unit. The main objective of monitoring is to quantify stock change of soil organic carbon and emissions of CO2, CH4, and N2O resulting from the project scenario during the project crediting period, prior to each verification.

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;
- Parameters to be measured, including any parameters required for the selected model (additional to those specified in this methodology);

- Data to be collected and data collection techniques and sample designs for directly-sampled parameters;
- Modelling plan, if applicable;
- Anticipated frequency of monitoring, including anticipated definition of “year”;
- 10-year baseline re-evaluation plan, detailing source of regional (sub-national) agricultural production data and procedures to revise the baseline schedule of activities;
- 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.

Projects that involve more than one farm should record when each farmer within the project area enters into agreement to adopt regenerative land management practices. Each farmer should be given a unique ID. Their name, location of their lands, and date of entering into the agreement and leaving the agreement should be recorded.

9.3.1 Sample design

It is understood that application of this methodology may employ a range of potential sample designs including grid sampling, simple random samples, stratified samples, variable probability samples, multi-stage samples, etc. The sample design will be specified in the monitoring plan, and un-biased estimators of population parameters identified that will be applied in calculations.

For all direct-sampled parameters, the project monitoring plan will clearly delineate spatially the sample population and specify sampling intensities, selection of sample units and sampling stages (where applicable). The plan for statistical analysis of the measurements needs to be submitted as part of the sampling plan for project validation.

Random sampling schemes without prior stratification frequently produce relatively high uncertainties when estimating SOC stock changes. Grid or linear sampling patterns could produce biased results and require a high number of samples.

In general, variability in soil properties, including SOC stocks, increases as the project area grows. Numerous factors determine SOC heterogeneity at the landscape scale, including climate, topography, historical land use and vegetation, parent material, soil texture, and soil type. Stratifying the project area into homogenous strata defined by factors that influence SOC stocks will usually reduce errors associated with project-scale estimates of SOC stocks. The Soil Maps and Databases of the FAO SOILS PORTAL[12], e.g., the Harmonized World Soil Database, or locally available (digital) soil maps can help choose different strata. In addition, soil texture can be easily estimated in the field (Vos et al., 2016). Since land use and management history frequently align with existing fields, it is recommended to take field boundaries into account when delineating strata. Within each stratum, random sampling may be applied to ensure representativeness and avoid biases. Defined strata should remain stable over time.

It is recommended that the number of homogeneous sites (i.e., the number of strata) and soil composite samples are increased to the maximum that can be afforded. The number of years required to detect SOC stock changes decreases with increasing sample number. Compositing or bulking soil samples can help better represent spatial variability but might reduce the ability to detect SOC stock changes over time. It is therefore recommended to take at least 3-5 composite samples within each stratum for model validation (true-up) or when using Quantification Approach 2 measure and re-measure. For re-sampling purposes, georeferencing of sampling locations[13] and consideration of seasonal variability[14] is essential.

The number of samples to be taken within each stratum should be determined based on expected variance to reduce overall uncertainty. A pre-sampling of 5 to 10 soil samples per stratum can provide an estimate of SOC variance where no up-to-date soil data is available.

To optimize the sampling approach and delineate between Soil Management Zones intra-field stratification based on soil spatial variation analysis using remote sensing is permitted. If applied, this may result in the number of samples required. For more details on this approach see Appendix 6: Method for intra-field stratification based on soil spatial variation.

A power analysis can be conducted to calculate the number of samples required to enable accounting of a minimum detectable difference, following these equations (FAO, 2019):

$$MDD \geq \frac{S}{\sqrt{n}} \times \left(t_{\alpha,v} + t_{\beta,v}\right) \qquad \text{(Equation 60)}$$

Where:

MDD = minimum detectable difference

S = standard deviation of the difference in SOC stocks between t_0 and t_1

n = Number of samples

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[12] http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/en/

[13] Depending on the available GPS precision, these locations may be delineated as areas of several meters in diameter.

[14] Sampling and re-sampling campaigns after several years should be conducted during the same season

$v = n - 1$ = degrees of freedom for the relevant t-distribution

t = values of the t-distribution given a certain power level (1-β) and α level (i.e. significance level)

$$n \geq \left(\frac{S \times (t_\alpha + t_\beta)}{MDD}\right)^2 \quad \text{(Equation 61)}$$

Where:

t_α = two-sided critical value of the t-distribution at a given significance level (α) frequently taken as 0.05 (5%);

t_β = one-sided quartile of the t-distribution corresponding to a probability of type II error β (e.g. 90%).

Further guidance on stratification and sampling strategies over large scales can be found in (Hengl, Rossiter and Stein, 2003; Aynekulu et al., 2011; de Gruijter et al., 2016; Vanguelova et al., 2016; Maillard, McConkey and Angers, 2017; ISO, 2018, p. 18; FAO, 2019; Mudge et al., 2020).

9.3.2 Modelling plan

Where Quantification Approach 1 or 3 is applied, the project monitoring plan will identify the model(s) selected initially and document analysis and results demonstrating validation of the model(s). Model validation datasets will be identified and archived to permit periodic application to calculate model prediction error. The modeling plan specifies the baseline schedule of agricultural management activities for each sample unit (fixed ex ante). Parameter tables will be developed for all model input variables (un-defined in the methodology) using the tables formats in Section 9.2 above.

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56. Yakubova, G. et al. (2019) 'Application of Neutron-Gamma Analysis for Determining Compost C/N Ratio', Compost Science & Utilization, 27(3), pp. 146–160. doi: 10.1080/1065657X.2019.1630339.

Appendix 1: non-exclusive list of potential improved regenerative land management practices

The following list represents the main categories of practices expected to enhance SOC stocks and/or reduce GHG emissions from soils under a broad range of cropping and livestock systems. However, the list is non-exhaustive; there are many other improved agricultural land management practices with the potential to enhance SOC stocks and/or reduce GHG emissions as well as emerging practices (e.g., soil inoculants). Furthermore, the terms used to denote the same or similar practice can differ widely from region to region. Therefore, for the purposes of demonstrating eligibility (i.e., applicability condition 1) as well as additionality (i.e., step 2 common practice) the project proponent must reasonably demonstrate that the implementation of a proposed practice constitutes an improvement over the pre-existing practice within the specific cropping and/or livestock system in the project region.

Reduce tillage/improve residue management
- Reduced tillage/Conservation tillage
- Strip-till/Mulch-till
- Continuous no-till
- Crop residue retention

Improve crop planting and harvesting
- Rotational commercial crop
- Continuous commercial crop with cover crop
- Rotational commercial crop with cover crop
- Double cropping
- Relay cropping
- Intercropping of cover crop with commercial crop (e.g., improved agroforestry) during the same growing season
- Incorporate fungal/microbial inoculant or other soil probiotic
- Utilisation of integrated pest management using biological controls

Improve grazing management
- Rotational grazing (also known as cell and holistic grazing)
- Adaptive multi-paddock grazing (rotational, livestock numbers are adjusted to match available forage as conditions change)
- Multi-species grazing
- Grazing of agricultural residues post-harvest and cover crops

Application of soil additives
- Replacement of synthetic fertilizer with organic fertilizer
- Application of organic soil additives (excluding fertilizers and biochar)
- Application of inorganic soil additives which have been approved under the SOCIALCARBON Standard.

Appendix 2: Procedure to demonstrate degradation of project lands in the baseline scenario

According to the IPCC, up to one quarter of the earth's ice-free lands are affected by land degradation[15] caused by direct or indirect human-induced processes. This equates to hundreds of millions of hectares of degraded crop- and grasslands with reduced productive capacity, which adversely affects livelihoods and ecosystems and the ability to meet humanity's growing needs. Degraded lands can be restored and rehabilitated through implementation of regenerative land management strategies, thereby reversing degradation and restoring productivity. In addition, such strategies can reduce conversion pressure on native ecosystems, generate new income opportunities, and provide ecosystem services such as erosion control, regulation of groundwater recharge, and enhanced above- and belowground biodiversity and carbon stocks. Given the multiple benefits of restoration, this methodology seeks to incentivize restoration of degraded crop- and grasslands by making an exception to the land use change applicability condition that otherwise requires project lands to remain cropland or grassland throughout the project crediting period. This exception, however, requires a two-step process to credibly demonstrate 1) current and future degradation of lands in the baseline scenario, and 2) expected improvements in soil health and associated socioenvironmental outcomes through the introduction of improved practices involving land use change.

1. **Demonstration of land degradation.** The project proponent shall use the *CDM Tool for the identification of degraded or degrading lands for consideration in implementing CDM A/R project activities*[16] to demonstrate both that the land is degraded at the start of the project and that the land will continue to degrade in the baseline scenario. The Tool uses a two-stage process that involves:
    a. identification of project lands classified as degraded under any verifiable local, regional, national or international land classification system or credible study produced within the last ten years; or
    b. in the absence of such study, through direct evidence based on indicators of degradation or through comparative studies. Exact procedures are outlined in the Tool.

2. **Demonstration of expected improvements resulting from project implementation.** The project proponent shall provide an analysis of how the proposed project activities will lead to restoration of project lands. Such analysis shall be based on the degradation indicators identified in Step 1 and shall at minimum include expected impacts on soil health, plant (i.e., crops, forage) productivity, biodiversity, local ecosystems, and livelihoods. Evidence types may include relevant local, regional, national or international studies and local expert analysis. Any experts consulted as part of the analysis should have at least 10 years of relevant experience in the project region and professional credentials (e.g., research scientist, certified agronomist).

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[15] Olsson, Lennart, et al. "Land Degradation: IPCC Special Report on Climate Change, Desertification, Land 5 Degradation, Sustainable Land Management, Food Security, and 6 Greenhouse gas fluxes in Terrestrial Ecosystems." IPCC Special Report on Climate Change, Desertification, Land 5 Degradation, Sustainable Land Management, Food Security, and 6 Greenhouse gas fluxes in Terrestrial Ecosystems. Intergovernmental Panel on Climate Change (IPCC), 2019. 1. Available at https://www.ipcc.ch/site/assets/uploads/sites/4/2019/11/07_Chapter-4.pdf.

[16] Available at https://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-13-v1.pdf.

Appendix 3: guidance on potential emerging technologies to measure SOC stocks

As indicated in Table 5 and Table 6 and parameter table (section 9.2) related to modelled, or modelled and measured SOC, projects may use emerging technologies to determine SOC content if sufficient scientific progress has been achieved in calibrating and validating measurements, and uncertainty is well-described. This appendix provides guidance on requirements for using such emerging technologies and a non-exhaustive list of potential technologies (with a focus on proximal sensing) to determine SOC content and criteria to ensure their robustness and reliability.

The applicability of a selected technology to measure SOC in a project must be demonstrated in several peer-reviewed scientific articles. In particular, project proponents should provide evidence of the ability of an emerging technology to predict SOC content with sufficient accuracy through the development and application of adequate calibration with data obtained from classical laboratory methods, such as dry combustion. The site characteristics for the underlying calibration must match the project site conditions, including range of SOC stocks, soil types, land use, etc. While projects may use the services of companies measuring SOC, the specificities of the applied measurement technology, including calibration methods, must be made available for review by a VVB. Unless a SOCIALCARBON Approved Service Provider, the service provider must not have restricted access through intellectual property rights.

Table 7 presents potential emerging proximal sensing technologies which research and publications have shown to hold promise for streamlining SOC measurement. Although proximal sensing techniques may not be as precise per individual measurement compared to conventional analytical laboratory methods, e.g., dry combustion, proximal sensing may be more cost-efficient and provide a better balance between accuracy and cost. Hence, although each individual measurement may be less accurate, many more measurements can be made across time and space than would be feasible with conventional methods, enabling an overall estimate of carbon stock that is of similar or better accuracy than lower density sampling that is measured with conventional analytical laboratory methods. Since many more proximal devices may be used in a project than would be used if all samples were sent to a single lab, care must be taken to demonstrate device to device calibration and precision. Project developers must provide details to the VVB on the criteria and considerations of the emerging SOC measurement technology as specified in Table 7. Projects should maintain adherence to these criteria over time to ensure that measurement and re-measurement are conducted under the same conditions and are thus comparable. While the focus is on proximal sensing, the Social Carbon Foundation is tracking developments related to remote (e.g., satellite) sensing of SOC stocks and future revisions to this appendix may include guidance on using remote sensing for direct SOC measurement if that technology is demonstrated as scientifically credible.

Table 7: Criteria to evaluate the use of emerging technologies based on proximal sensing to measure SOC content

Method	Criteria and considerations to ensure robustness and reliability
Inelastic neutron scattering[17] (INS)	• If carbonates are present (calcareous or limed soils), inorganic C must be separately accounted for. • Inorganic gamma scintillators (detectors based on the sodium iodide NaI(Tl), bismuth germinate BGO, and lanthanum bromide $LaBr_3(Ce)$) are better suited due to their higher efficiency of registering gamma rays in the energy range up to 12 MeV. • Pulsed Fast/Thermal Neutron Analysis (PFTNA) is the most suitable for soil neutron-gamma analysis. It allows separating the gamma ray spectrum due to INS reactions from the thermal neutron capture and the delay activation reaction spectra. • Locally adapted calibration procedures must be included in the project documentation for VVB review.
Laser-induced breakdown spectroscopy (LIBS)	• Soil samples must be dried for at least 24h at 40°C. • If carbonates are present (calcareous or limed soils), samples must be acid-washed. • Soil samples must be milled for homogenization and particle size reduction to facilitate the evaporation and atomization process in the plasma. • Before analysis, soil material must be pressed to form a pellet with a flat surface. • When measuring directly in the field (in-situ), appropriate corrections to remove soil moisture and further matrix effects must be applied. • The configuration of the LIBS instrumental parameters should be optimized for each matrix. The laser pulse energy and the diameter of the laser beam (i.e., spot size) should be monitored simultaneously in the laser pulse fluence term (laser pulse energy per unit area, J cm^{-2}) as well as delay time, laser repetition rate, etc. • Projects may rely on chemometric methods for signal analysis, spectral preprocessing, and subsequent data processing and interpretation, including reducing matrix effects. • A description of the locally adapted calibration procedures must be included in the project documentation for VVB review. Multiple linear regression has proven to be an effective calibration strategy to tackle interference in soil carbon analysis. Further "non-traditional calibration strategies"[18] may be applied, which explore the plasma physicochemical properties, the use of analyte emission lines/transition energies with different sensitivities, the accumulated signal intensities, and multiple standards to obtain a linear model or calibration curve. • Multiple laser shots per sample may improve the measurement results.

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[17] Also known as neutron-stimulated gamma ray analysis or spectroscopy)

[18] Described in Fernandes Andrade, Pereira-Filho and Amarasiriwardena, 2021 and Costa et al., 2020

Mid-infrared (MIR) and visible near-infrared (Vis-NIR and NIR) spectroscopy, including diffuse reflectance spectroscopy (DRS) and diffuse reflectance infrared Fourier transform (DRIFT) measurements	• For MIR and NIR, soil samples must be air or oven-dried, crushed or sieved to a size fraction smaller than 2 mm, avoiding preferential sieving. • When measuring directly in the field (in-situ), appropriate corrections to remove soil moisture and further matrix effects must be applied. • The applied spectrometer should have a spectral resolution of 10 nm or less across the visible and near-infrared range (between 400 and 2500 nm), and spectra should be recorded in this range at 1 nm intervals. • Measurement protocols should be used when available, such as Appendix B in Viscarra Rossel et al., 2016 for Vis-NIR or the Standard Operating Procedures of the Soil-Plant Spectral Diagnostics Laboratory of World Agroforestry Centre (ICRAF) • Calibration through multivariate statistics or machine-learning algorithms has been performed using large spectral libraries[19] or new site-specific libraries developed with local soil samples (higher accuracy). Sub-setting or stratifying the dataset can provide better calibration results. See (England and Viscarra Rossel, 2018) and (Stevens et al., 2013) for further guidance on calibration techniques and spectroscopic model development and validation. • Calibration procedures must be included in the project documentation for VVB review.

The following scientific publications provide more details and further guidance on the application of the above-listed technologies to measure SOC:

INS

- Izaurralde, R. C. et al. (2013) 'Evaluation of Three Field-Based Methods for Quantifying Soil Carbon', PLOS ONE, 8(1), p. e55560. doi: 10.1371/journal.pone.0055560.
- Kavetskiy, A. et al. (2017) 'Neutron-Stimulated Gamma Ray Analysis of Soil', in New Insights on Gamma Rays. Intech Open. Available at: https://www.intechopen.com/books/new-insights-on-gammarays/neutron-stimulated-gamma-ray-analysis-of-soil.
- Yakubova, G. et al. (2019) 'Application of Neutron-Gamma Analysis for Determining Compost C/N Ratio', Compost Science & Utilization, 27(3), pp. 146–160. doi: 10.1080/1065657X.2019.1630339.

LIBS

- Costa, V. C. et al. (2020) 'Calibration Strategies Applied to Laser-Induced Breakdown Spectroscopy: A Critical Review of Advances and Challenges', 31(12). doi: https://doi.org/10.21577/0103-5053.20200175.
- Fernandes Andrade, D., Pereira-Filho, E. R. and Amarasiriwardena, D. (2021) 'Current trends in laserinduced breakdown spectroscopy: a tutorial review', Applied Spectroscopy Reviews, 56(2), pp. 98–114. doi: 10.1080/05704928.2020.1739063.
- Senesi, G. S. and Senesi, N. (2016) 'Laser-induced breakdown spectroscopy (LIBS) to measure quantitatively soil carbon with emphasis on soil organic carbon. A review', Analytica Chimica Acta, 938, pp. 7–17. doi: 10.1016/j.aca.2016.07.039.

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[19] such as the African ICRAF-ISRIC Soil Spectra Library, the multispectral data collected in the European LUCAS topsoil database, the USDA NRCS (KSSL) National Soil Survey Center mid-infrared spectral library or the Australian soil visible near infrared spectroscopic database described in (Viscarra Rossel and Webster, 2012)

MIR and (Vis-)NIR, incl. DR and DRIFT spectroscopy

- Barthès, B. G. and Chotte, J.-L. (2021) 'Infrared spectroscopy approaches support soil organic carbon estimations to evaluate land degradation', Land Degradation & Development, 32(1), pp. 310–322. doi: 10.1002/ldr.3718.
- Dangal, Shree R.S., Jonathan Sanderman, Skye Wills, and Leonardo Ramirez-Lopez. 2019. "Accurate and Precise Prediction of Soil Properties from a Large Mid-Infrared Spectral Library" Soil Systems 3, no. 1: 11. https://doi.org/10.3390/soilsystems3010011
- England, J. R. and Viscarra Rossel, R. A. (2018) 'Proximal sensing for soil carbon accounting', SOIL, 4(2), pp. 101–122. doi: 10.5194/soil-4-101-2018.
- Ng, W., Minasny, B., Jones, E. and McBratney, A. (2022) 'To spike or to localize? Strategies to improve the prediction of local soil properties using regional spectral library', Geoderma, 406, https://doi.org/10.1016/j.geoderma.2021.115501
- Nocita, M. et al. (2015) 'Chapter Four - Soil Spectroscopy: An Alternative to Wet Chemistry for Soil Monitoring', in Sparks, D. L. (ed.) Advances in Agronomy. Academic Press, pp. 139–159. doi: 10.1016/bs.agron.2015.02.002.
- Reeves, J. B. (2010) 'Near- versus mid-infrared diffuse reflectance spectroscopy for soil analysis emphasizing carbon and laboratory versus on-site analysis: Where are we and what needs to be done?', Geoderma, 158(1), pp. 3–14. doi: 10.1016/j.geoderma.2009.04.005.
- Sanderman J, Savage K,Dangal SRS. Mid-infrared spectroscopy for predictionof soil health indicators in the United States. Soil Sci.Soc. Am. J. 2020;84:251–261.https://doi.org/10.1002/saj2.20009
- Seybold, C.A., et al., 'Application of Mid-Infrared Spectroscopy in Soil Survey', Soil Sci.Soc. Am. J. 2019; 83: 1746-1759. https://doi.org/10.2136/sssaj2019.06.0205
- Stevens, A. et al. (2013) 'Prediction of Soil Organic Carbon at the European Scale by Visible and Near InfraRed Reflectance Spectroscopy', PLOS ONE, 8(6), p. e66409. doi: 10.1371/journal.pone.0066409.
- Viscarra Rossel, R. A. et al. (2016) 'A global spectral library to characterize the world's soil', EarthScience Reviews, 155, pp. 198–230. doi: 10.1016/j.earscirev.2016.01.012.
- Viscarra Rossel, R. A. and Webster, R. (2012) 'Predicting soil properties from the Australian soil visible– near infrared spectroscopic database', European Journal of Soil Science, 63(6), pp. 848–860. doi: 10.1111/j.1365-2389.2012.01495.x.

Appendix 4: SOCIALCARBON Approved Service Providers

Significant progress has been made on SOC measurement through remote sensing over the past years. Several companies have developed proprietary methodologies to quantify SOC fluxes which are not open source. To accommodate these service providers and their clients, SOCIALCARBON is permitting these service providers to become Approve Service Providers. **All SOCIALCARBON Approved Service Providers for this methodology will be published on the SOCIALCARBON website.**

To become a SOCIALCARBON Approved Service Provider, organisations must demonstrate that their model can generate accurate estimates. The Social Carbon Foundation will provide the Service Provider a number of shapefiles from different geographic locations with SOC stocks known only to the Social Carbon Foundation. The Service Provider must submit their estimated SOC stocks for the different areas which will be reviewed by the Social Carbon Foundation team. The Service Provider will be notified if they have been approved, which geographic regions their model is authorised for use, and any discounts that projects using the model must apply to SOC carbon estimates (if necessary).

In addition, the service provider must provide evidence of the applicability of their selected technology to measure SOC in a project which must be demonstrated in several peer-reviewed scientific articles. In particular, project proponents should provide evidence of the ability of an emerging technology to predict SOC content with sufficient accuracy through the development and application of adequate calibration with data obtained from classical laboratory methods, such as dry combustion. The site characteristics for the underlying calibration must match the project site conditions, including range of SOC stocks, soil types, land use, etc.

The specificities of the applied measurement technology, including calibration methods and input parameters must be available for review by a VVB. It is the responsibility of the SOCIALCARBON Approved Service Provider to establish a legally-enforceable agreement with the VVB to protect their intellectual property rights.

Projects using a SOCIALCARBON Approved Service Provider must document the measurement technology applied, input parameters and service provider used. It is the responsibility of the SOCIALCARBON Approved Service Provider to establish a legally-enforceable agreement with the project proponent to protect their intellectual property rights and ensure confidential information (related to their methodology) is not publicly shared on the SOCIALCARBON Registry.

Any revisions to the methodology must be documented and shared with the Social Carbon Foundation.

In the event that a SOCIALCARBON Approved Service provider is being used by a project proponent and is no longer available (e.g. due to closure of the organisation), the project proponent shall select an open source modelled approach most similar to the SOCIALCARBON Approved Service Provider's methodology. This alternative model approach shall be documented with evidence demonstrating its comparability with the previous approach used. The previous monitoring periods values shall be re-assessed using the new model to determine the change in SOC stocks for the latest monitoring period.

The Social Carbon Foundation has sole discretion to approve or decline an application to become a SOCIALCARBON Approved Service Provider. Applications can be made to operations@socialcarbon.org.

Appendix 5: Considerations for Approaching Uncertainty in Remote Sensing Measurements

Accuracy of Model for Variable Prediction

Remote sensing (RS) techniques offer a reduction in the sample error normally associated with low-density sample designs from ground measurements. The prediction of values per unit of area (e.g. pixel, polygon) provides an extensive representation of the spatial variability of biophysical factors within a project area. This is especially relevant for large projects where the infrastructure for scaling up samples is costly or unavailable.

Ground samples are considered accurate when applying recognized QA/QC procedures for field data collection. QA/QC procedures ensure a significant reduction of the systematic component (bias) of the measurement errors (aggregated to the uncertainty deduction) in the emission/carbon inventory of the project.

Although, RS techniques require a different approach to ensure accurate measurements within an acceptable confidence interval (approaching real physical values). The ideal RS tool must integrate an accurate prediction model in terms of **unbiased** and **precise** estimations.

The method for assessing RS accuracy must be selected based on the type of model and the availability of data for model training and accuracy testing. While precision is generally inferred from the model error distribution, the use of testing datasets (independent from model training) is recommended to ensure unbiased accuracy prediction.

Considering these conditions, methods like the root mean square error (RMSE) can be implemented to predict the accuracy of the model:

Where $z(\mathbf{x}i)$ represents the set of know values and $\hat{z}(\mathbf{x}i)$ the set of predicted values.
Nevertheless, a complete approximation to the accuracy of the prediction requires reporting underlying metrics related to Mean Error, precision (e.g., R-Squared, RPD, RPIQ, standard deviation of the error) and/or bias:

$$bias = \frac{1}{n}\sum_{i=1}^{n}(observed_i - predicted_i)$$

where, $predicted_i$ and $observed_i$ are the predicted and observed values at the time *i*; *n* is the number of total samples.

Several drawbacks pertain to accuracy:

- It can contain a bias, which is unknown and requires an independent dataset for testing.
- It does not directly provide the uncertainty of each individual prediction; the latter changes along the range of the measure and Y. although RMSE is a correct summary statistic for guiding the model-selection process (e.g., optimal data pre-treatment), it cannot lead to prediction intervals with good coverage probabilities.

- It is very dependent on the statistical distribution of the values of the validation-sample set. It is therefore necessary to come back to the evaluation of the uncertainty for each new prediction to understand the relationships between the individual uncertainties, the RMSE and the distribution of the sample set.

Sources of Uncertainty in RS Measurements

Uncertainty is an expression of confidence about our knowledge and is, therefore, subjective. Uncertainty assessment is essential for establishing the value of data as inputs to decision making and for judging the reliability of decisions that are informed by the data. It is also important for determining the causes of uncertainty in environmental research and for directing resources toward improving data quality.

RS measurements are the result of the transformation of multispectral data observed at a specific point in space and time. The most adequate model for transformation of these spectral data must be selected according to the characteristics of the variable studied: continuous or discrete, linearity or non-linearity, fuzzy or crisp classification, etc.

Considering the spatial nature of the model, uncertainty in the prediction model is also attributed to the location (position in space) as a function of the input variables (independent of model parameters) and the spatial support (area covered by the prediction known as Effective Resolution Element, ERE). This spatial relationship between model variables can be illustrated as follows:

$$z_v(\boldsymbol{u}) = f(\boldsymbol{y}_v(\boldsymbol{x}), \theta)$$

Where *z* is the predicted variable, ***y*** is a vector of input variables (e.g. spectral bands), *V* is the spatial support of ***y*** and *z,* x represents the location of ***y*** and *z.* The prediction model is represented by f and **ϴ** is the vector of the parameters of this model.

It must be noted that the pixel boundaries are not fixed and is not possible to obtain an absolute value for the spatial support, however, an estimation can be derived from the grid cell size of the image. This aspect is important considering how the prediction model performance varies with inputs at different pixel resolution (support) are employed.

Similarly, location relates to the uncertainty generated from the relationship between spectral data and ground measurements and the transformation into raster data. Different uncertainty metrics for location can be obtained from the selection of test ground points (e.g., root mean square error and error distribution).

Parametric and model uncertainty are considered global for the mapped area, while location uncertainty is attributed to single pixels. However, a multi-pixel approach for spatial uncertainty is required to determine the uncertainty attributed to a specific variable in a set of joint contiguous locations.
Other important sources of uncertainty can emerge from factors related to the data inputs of the model including i) sample preparation, ii) spectrum pre-treatment, iii) geological heterogeneity, iv) reference data and v) calibration method.

Therefore, it is important to consider the quality of the spectral inputs of the model and how this can affect the prediction accuracy of RS. Applying pre-treatment techniques to the spectral data such as averaging, centering, smoothing, standardization, normalization, etc., can significantly reduce spectral noise and increase the robustness of RS estimations.

Finally, after the prediction model has gone through calibration and validation, tests for goodness of fit are recommended to compare the results of predicted values in comparison to actual measured values (e.g., R-squared, RMSE).

Considerations for remote sensing-based soil measurements

The aspects described so far address general assumptions about RS measurement techniques for non-specific variables. However, variables for soil analysis have distinctive characteristics that should be considered when defining an appropriate RS technique (type of sensor, prediction model, uncertainty determination, calibration method, etc.). The distribution of soil related properties is usually asymmetric (skewed), and RS techniques addressing similar properties (crop, vegetation, etc.) but with normal distribution are not adequate for soil analysis.

Example of uncertainties reported through an RS method for SOC prediction

The example RS method for SOC prediction integrates the soil spectral data registered per pixel and applies a neural network (NN) model trained on reference soil data to predict SOC content. These results are transformed and calibrated into SOC stocks (t/ha) at a given time. However, predicting the long-term evolution of SOC stocks requires the integration of these estimates into a process-based biochemical model (e.g., DayCent, RothC, DNDC, etc.).

- There is inherently variability on the NN model prediction per pixel. The observed variability is higher in certain pixels due to external conditions (model-independent). Considering this, pixel-based uncertainty is reported as a composed Confident Interval (CI) of the prediction.
- To reduce the bias of the prediction an offset correction (model calibration) of the results based on ground measurements should be applied.
- Input variables of the model such as Bulk Density (BD) are dependent on the predicted SOC. Thus, it is important to consider an error of this assumption in the CI.

Uncertainty in Map Classifications

Thematic classification maps are composed of distinctive classes of a variable assigned to individual pixels. These mutually exclusive classes are created through classifier algorithms that process the data acquired through remote sensing (hyper- and multispectral images, RADAR, LiDAR, etc.) and registered in single pixels.

Common methods for defining the thematic error associated with these classifications are derived from the comparison of ground data with the obtained map (e.g., confusion matrix). These global statistics are reported for assessing the accuracy of the overall map classification and the class specific accuracies (user’s and producer’s accuracy). While some continuous value modelling approaches also extrapolate, classifications can only ever consider those classes that are also included in the training and validation dataset.

However, a more complex approximation to local statistics is required to account for the spatial variation in quality from the different classes in the map. In this case, approaches like maximum likelihood, random forest and other neural network classifiers could be applied to describe the spatial distribution of the thematic uncertainty and provide accuracy metrics on the allocation of classes in single pixels (reliability).

RS inputs in SOC Biochemical Models

The uncertainty introduced from input data to run biochemical models for monitoring C carbon stocks is affected by the quality of the variable measurements (e.g., initial SOC content, soil texture, climate, etc.).

RS measurements have an inherently higher measurement error than ground samples but generally contribute to a lower propagation of error derived from the sampling design.

In order to determine these effects, a Monte Carlo simulation can be applied (as part of the Bayesian model calibration) to propagate uncertainty through the model and provide prediction intervals associated with the inputs from RS measurements. This method offers the advantage of addressing dependencies between the model parameters and the presence of asymmetric error distributions (other than Gaussian distribution).

The following should be considered when running a biochemical soil model (e.g. DayCent, Roth-C) with initial inputs from RS measurements:

- The overall set of uncertainty metrics from RS measurements is not required for model computations, but ideally an uncertainty range (for instance a mode or median, a min and a max value) should be provided as input to the model based on the uncertainty propagation method performed (e.g., Monte Carlo method).
- The accuracy of the RS inputs against ground measurements (e.g., RS-predicted SOC vs. soil sampling) is not tested by the process-based model per se. However, a comparison between the outputs of ground and RS measurements can be used to validate RS approaches.
- Besides the advantages of the Monte Carlo simulation method for determining uncertainty, there may be limitations related to the tools and computer power required to run thousands of the simulations at high spatial and temporal resolution. Moreover, Monte Carlo is bias towards very large number of runs (because the results will skew towards mean values).

Key Literature Addressing the Described Approaches on Remote Sensing Uncertainty

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Appendix 6: Method for intra-field stratification based on soil spatial variation

The SOC distribution in agricultural fields is influenced by environmental variables such as topography, climate, soil texture, mineralogy, and water regime. Additional variability results from historical land use, crops/cropping pattern and agricultural management practices. The combined effect of these factors leads to noticeable spatial variability in SOC, even within a given field. To effectively monitor carbon stocks in agricultural soils with a minimum number of soil samples, a stratified sampling based on the spatial variability detected in a given field can offer the most appropriate statistical approach.

The delineation of Soil Management zones (SMZ) is a method used in precision agriculture for the purpose of stratification and can be applied to determine the SOC distribution in agricultural fields. As the variability of soil properties within a SMZ is strongly reduced, fewer samples are sufficient to get an unbiased estimate of SOC. The stratification itself can be derived in different ways, including the use of remote sensing satellite data.

Considering the increasing accessibility and robustness of hyper- and multispectral data for determining spatial heterogeneity, the following recommended approach is based on the use of multi-temporal remotely sensed time series (minimum 3 to 5 years). The analyzed multi-spectral image stack not only focuses on bare soil images but uses the observed vegetation productivity under different crops and weather patterns as proxies for the underlying soil properties. Combined with additional geo-layers and variables, the resulting SMZs define the strata for a subsequent random sampling and achieve a substantial reduction in the number of physical samples required for carbon stock monitoring.

This SMZ approach can be summarized in four procedural steps:

1. Preparing data layers
2. Clustering of homogeneous areas and within-field segmentation
3. Delineation of SNZ
4. Stratified random sampling

Step 1: Preparing data layers

SMZ delineation starts by acquiring data layers for characterizing spatial variability. The set of data layers can be integrated from a combination of environmental, crop, and spectral attributes indicative of soil boundaries and SOC distribution. Recommended proximal and remote sensing indicators for measuring soil and vegetation spatial variability are gamma ray, electromagnetic induction (EMI), visible and near-infrared (vis-NIR) spectroscopy, as well as a plethora or soil/vegetation related spectral indices such as the normalized difference vegetation index (NDVI).

In practice, however, the acquisition and implementation of sensors and field measurement technology (e.g., gamma ray, EMI) results costly at a large scale. Hence, the use of freely available high resolution Earth Observation (EO) data from satellite platforms such as Landsat/Sentinel-2 (to acquire multi-spectral data) or satellite-based imaging spectrometer (to acquired spectrally continuous vis-NIR spectra) is recommended. The EO datasets offer the additional benefit of acquiring frequent observations over multiple years, enabling the monitoring of long-term processes, such as SOC dynamics.

Representing temporal variability

Vegetation indexes (e.g., NDVI) can be used as a proxy for temporal variability of crop cover and biomass attributed to climate, and changes in agricultural management practices (e.g., tillage, fertilization, crop practices, and residue management). Besides using spectral indices, spatio-temporal variability in crop cover and biomass can also be retrieved using physically-based radiative transfer models (RTM) that provide a direct link between the observed multi-/hyperspectral signatures and the variables of interest (e.g., biomass and leaf area index).

Variability within the defined management period (minimum 3 to 5 years) is represented as a temporal dimension (z) within the multi-temporal dataset (including remotely sensed and other geodata).

After composing the multi-variate datasets for characterizing spatiotemporal variability in soil properties, project proponents should perform a series of statistical tests to further characterize the spatial structure in the individual fields:

- Data distribution – histograms, skewness, kurtosis
- Spatial autocorrelation – Moran I
- Spatial autocorrelative structure – Semivariance statistic, semivariogram.
- Fit of variogram models – based on parameters including coefficient of determination (R^2), reduced sums of squares (RSS), and root mean square error (RMSE).

Step 2: Clustering of homogeneous areas and within-field segmentation

A clustering procedure should then applied to the dataset to create spatially continuous segments composed of variables with similar attributes. There is no rule of thumb for the selection of a segmentation algorithm (e.g., MeanShift), but some techniques will be more effective at processing data with specific characteristics, for example, a high-dimensional time series dataset.

When handling multi-variate datasets, principal component analysis (PCA) can be applied to compress individual variable attributes into fewer components before working with the cluster algorithm.

However, the use of non-linear compression techniques (e.g., unsupervised deep learning algorithms) over approaches that assume linear relations between variables are recommended.

Step 3: Delineation of SMZ

The resulting cluster boundaries should be used to delineate the initial SMZ. Once the first SMZ classes are created, these can be transformed to improve the map homogeneity through buffering, merging, filtering, reclassification, and similar techniques. These measures are effective for handling with the detrimental effects of field boundaries and achieve a manageable shape and size of the resulting segments.

For instance, the distortion attributed to the 'mixed' nature of sensor readings in transition areas (e.g., between the field and the field boundary) can be improved by applying a buffer technique to redraw the field boundaries. With respect to shape and size of the segments, the ideal segments will remain compact and assure a minimal practical size for the subsequent stratified sampling.

Finally, the effectiveness of SMZ for representing spatial variation must be tested through several geostatistical approaches (mentioned in Step 1) to ensure that the within-segment variability (and spatial autocorrelation, etc.) is significantly reduced compared to the variability and autocorrelation found in the total field.

Step 4: Stratified random sampling

Stratified random sampling makes use of the previously derived strata (e.g., SMZs), to increase the accuracy of estimates over the studied effect and account for variability. In statistical surveys, when subpopulations within an overall population present (structured) variation, it is a well-established knowledge that sampling each subpopulation independently can increase accuracy.

In this respect, the obtained SMZ classes represent areas of homogenous spatial variability and are indicative of the expected distribution of soil parameters. Therefore, these can be used to define the strata for performing the stratified random sampling and define the point coordinates where soil sampling is required for monitoring (e.g., for the monitoring of the evolution of the carbon stock).

The optimal number of samples required is determined based on the number of strata and the size of the individual stratum in relation to the total project area. Nevertheless, the definition of samples required for each individual project can be influenced by the costs and desired accuracy.

Appendix 6: General Requirements for Soil Sampling

Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QC procedures available from published handbooks is recommended, such as those produced by FAO and available on the FAO Soils Portal, the ISO standards on soil sampling (including ISO 18400-104 Soil quality — Sampling — Part 104: Strategies) or the IPCC Good Practice Guidance LULUCF 2003.

For all directly sampled parameters, the project monitoring plan must clearly spatially delineate the sample population and specify sampling intensities, selection of sample units and sampling stages (where applicable). The statistical analysis measurements plan must be submitted as part of the sampling plan for project validation. The detailed sample design must be specified in the monitoring plan, and unbiased estimators of population parameters identified for application in calculations.

- For re-sampling purposes, it is essential to georeference sample locations[20] and consider seasonal variability.
- Sampling and re-sampling campaigns must be conducted during the same season over time.
- Where organic amendments are applied, projects should delay sampling or re-sampling to the latest time possible after the previous application and the shortest time possible before the next application.

Sampling Design: Stratified Random Sampling

Soil sampling must be conducted following the stratified random sampling strategy[21].Each sampling unit within the project area should be divided into homogenous strata based on factors influencing SOC stock distribution (see below). Random samples should be taken in each stratum.

Project-specific strata, their area and the sampling points within strata must be reported in a spreadsheet and submitted as an annex to project documentation at every verification.

The stratified random sampling strategy may be nested within a multi-stage sampling approach, but in such cases stratified random sampling must be employed in the stage directly before the sample point stage (see Appendix 6 for an example). An alternative sampling strategy may be proposed for a project via a methodology deviation that provides sufficient scientific rationale and project-specific justification.

Random sampling schemes, without prior stratification, frequently produce relatively high uncertainties when estimating SOC stock changes. Grid or linear sampling patterns require a large number of samples and may produce biased results due to linear features across the site being under- or over-represented. Therefore, grid or linear sampling patterns are not recommended.

- To determine strata, the best available data on factors expected to affect the response of SOC stocks to the project activities must be used.
- Projects must report the factors used in stratification and how strata were developed.

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[20] Depending on the available GPS precision, these locations may be delineated as areas of several meters in diameter.

[21] Detailed descriptions of how to conduct stratified random sampling are provided in Annex 3 in FAO (2020) and in Module B in World Bank (2021).

Numerous factors determine SOC heterogeneity at field (10–100 ha) and landscape (100– 1000 ha) scales, including climate, topography, historical land use and vegetation, parent material, soil texture and soil type. Stratifying the project area (or sampling units) into homogenous strata defined by factors that influence SOC stocks should improve sampling efficiency and reduce errors associated with project-scale estimates of SOC stocks.

The sampling design must capture variability within the project area. An unbiased spatially stratified approach is important to capture variations in SOC across the project area. The larger a stratum's area and the greater the expected or known variability within a stratum, the higher the number of samples that must be taken within the stratum. The soil maps and databases of the FAO SOILS PORTAL[22] (e.g., the Harmonized World Soil Database), SoilGrids[23] or locally available (digital) soil maps may help in choosing different strata. In addition, soil texture is easily estimated in the field. Since land use and management history frequently align with existing fields, field boundaries should be taken into account when delineating strata, though potential changes in field boundaries over time must be considered. Defined strata should remain stable over time.

The number of homogeneous sites (i.e., the number of strata) and soil composite samples should be maximized. The number of years required to detect SOC stock changes decreases with increasing sample number. Compositing or bulking soil samples may better represent spatial variability but may reduce ability to detect SOC stock changes over time. Therefore at least 3–5 composite samples should be taken within each stratum for model true-up or when using Quantification Approach 2.

Collection of soil samples

The following are guidelines for collection of soil samples and reporting.

1) Soil sampling must follow established best practices, such as those found in FAO (2019, 2020), De Gruijter et al. (2006), Smith et al. (2020) and Soil Science Division Staff (2017).
2) Where possible, SOC content and soil mass should be obtained from the same sample, or alternatively from adjacent samples taken during the same sampling event. Where multiple cores are composited to create a single sample, these cores must be from the same depth and fully homogenized prior to subsampling.
3) All organic material (e.g., living plants, crop residue) must be cleared from the soil surface before soil sampling.
4) Soil mass must not include particles greater than 2 mm in diameter (i.e., gravel/stones) nor plant material[24].
5) Soil samples must be shipped within five days of collection and kept refrigerated until shipping if they are stored in sealed plastic bags. Alternatively, soil samples should be aerated during storage, avoiding mixing of the different soil materials. Drying and sieving procedures must follow laboratory-specific SOPs and be consistent for all samples collected as part of the project.

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[22] Available at: http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/en/

[23] Available at: https://soilgrids.org/

[24] Beem-Miller et al. (2016) provide a useful approach to ensuring high-quality sampling in rocky agricultural soils.

6) Reporting of SOC stock changes from direct measurements under Quantification Approaches 1 and 2 must occur on an equivalent soil mass (ESM) basis.
    a) The mass of soil in each depth layer depends on the bulk density of the respective layer. Therefore, it is important to differentiate between soil mass layers and soil depth layers to enable a consistent comparison of SOC changes and differences between two points in time and between baseline and project areas.
    b) SOC stocks and stock changes must be reported to a minimum depth of 30 cm. To eliminate the need for extrapolation outside of the measured range, soils must be sampled deeper than the minimum 30 cm required for reporting SOC stock changes.
    c) To enable the ESM approach, soil samples at re-sampling must be taken as contiguous cores divided into at least two increments.
    d) The project proponent may select the depth increments sampled according to expected loosening or compaction effects throughout the project lifetime, because bulk density changes as a result of regenerative ALM will depend largely on land use in the project area and the ALM practices implemented as part of the project.
    e) Where possible, soils should be sampled to 50 cm depth (i.e., in two depth increments 0–30 cm and 30–50 cm), following the recommendation in Wendt and Hauser (2013) to ensure sub-soil depth layers are sufficient to permit adjustments. From these measurements, the ESM layers and the depths to reference mass will be determined. Note that only the soil mass is required from the two separate depth increments. SOC content analysis may be performed on only one sample after mixing the two depth increments.
7) Soils less than 30 cm deep (e.g., due to shallow bedrock or a formed hardpan) must be sampled to the depth of the impeding layer. Sample units with these characteristics must be documented and SOC stocks must only be reported to the sampled depth[25].
8) Geographic locations of intended sampling points must be established prior to sampling. The location of both the intended sampling point and the actual sampling point must be recorded.
9) The number of samples to be taken within each stratum should be determined based on the expected variance, to reduce overall uncertainty. A pre-sampling of 5 to 10 soil samples per stratum may provide an estimate of SOC variance where up-to-date soil data are unavailable.
10) A power analysis may be conducted to calculate the number of samples needed to enable accounting of a minimum detectable difference, following the equations below (FAO, 2019). However, projects are not required to take this number of samples.

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[25] This will affect the ESM layers of the respective sampling points shallower than 30 cm