VCS Methodology

VM0042

IMPROVED AGRICULTURAL LAND MANAGEMENT

Version 2.2 – Tracked Changes (C&C)

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Sectoral Scope 14: Agriculture, Forestry and Other Land Use

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1 SUMMARY DESCRIPTION

Table 1: Additionality and crediting baseline methods

Additionality,Crediting Method and Mitigation Outcome	
Additionality	Project Method
Crediting Baseline	Project Method
Mitigation Outcome	Reductions and Removals

This agricultural land management (ALM) methodology provides procedures to estimate the greenhouse gas (GHG) emission reductions (CO_2, CH_4, and N_2O) and carbon dioxide removals (reductions and removals) resulting from the adoption of improved ALM practices. The methodology is compatible with regenerative agriculture and has a particular focus on increasing soil organic carbon (SOC) storage.

The crediting baseline and additionality are determined via a project method (Table 1~~Table 1~~). The baseline scenario assumes the continuation of pre-project ALM practices. Practices in the baseline scenario are determined by applying a minimum three-year historical look-back period to produce an annual schedule of activities (i.e., tillage, planting, harvest, and fertilization events) for each quantification unit within the project area (e.g., for each field), to be repeated over the baseline period.[1] Baseline emissions/stock changes are then modeled. Alternatively, baseline SOC stock change may be directly measured in "baseline control sites" managed according to pre-project practices as set out in the schedule of activities. The baseline scenario is re-evaluated as required by the most recent version of the *VCS Standard*, and revised, where necessary, to reflect current agricultural production in the region.

Additionality is demonstrated by a barrier analysis and showing that the practice change implemented under the project activity is not common practice. A practice change constitutes any of the following:

- Adoption of a new practice (e.g., adoption of one or more of the practices covered in the categories included in Applicability Condition 1);
- Cessation of a pre-existing practice (e.g., stop tillage or irrigation);
- Adjustment to a pre-existing practice; or
- Some combination of the above.

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[1] Project proponents must reassess ALM project baselines every ten years or every five years, where regional practice changes are more frequent and/or data becomes available to update the baseline. See the most recent version of the *VCS Standard* for further details on baseline reassessment requirements.

Any quantitative adjustment (e.g., decrease in fertilizer application rate) must exceed 5% of the pre-existing value to qualify as a practice change.

The methodology provides three approaches to quantifying reductions and removals resulting from the adoption of improved ALM practices.

Quantification Approach 1: Measure and Model – a biogeochemical, process-based model is used to estimate GHG fluxes related to SOC stock changes, soil methanogenesis, and use of nitrogen fertilizers and nitrogen-fixing species. Edaphic characteristics and actual agricultural practices implemented, measured initial SOC stocks, and climatic conditions in sample fields are used as model inputs. Periodic measurements of SOC stocks are required every five years at minimum (see Table 8~~Table 8~~).

Quantification Approach 2: Measure and Re-Measure – direct measurement is used to quantify changes in SOC stocks. This approach is relevant where models are unavailable or have not yet been validated or parameterized for a particular region, crop, or practice, or where project proponents prefer to use a direct measurement approach for SOC stock change. Quantification Approach 2 directly measures SOC stock changes in the baseline scenario in linked baseline control sites.

Quantification Approach 3: Default Factors – CO_2 flux from fossil fuel combustion and N_2O and CH_4 fluxes, excluding CH_4 flux from methanogenesis, are calculated using default emission factors.

The quantification approach varies by emission/removal type. Approaches to quantification of contributing sources of CO_2, CH_4, and N_2O emissions are listed in Table 5~~Table 5~~.

Project proponents must use the templates available on the *VM0042* webpage to prepare the documents required for project validation and verification.

2 SOURCES

This methodology is based on the following methodologies, modules, and tools:

- *VM0017 Adoption of Sustainable Agricultural Land Management, v1.0*
- *VM0022 Quantifying* N_2O *Emissions Reductions in Agricultural Crops through Nitrogen Fertilizer Rate Reduction, v1.1*
- *VM0026 Methodology for Sustainable Grassland Management, v1.1*
- *VMD0054 Module for Estimating Leakage from ARR Activities, v1.0*
- *VT0008 Additionality Assessment, v1.0*
- *VT0009 Combined Baseline and Additionality Assessment, v1.0*
- *VT0014 Estimating Organic Carbon Stocks Using Digital Soil Mapping, v1.0*

This methodology uses the most recent versions of the following Clean Development Mechanism (CDM) methodologies and tools:

- *AR-TOOL14 Methodological Tool: Estimation of Carbon Stocks and Change in Carbon Stocks of Trees and Shrubs in A/R CDM Project Activities*
- *Tool for Testing Significance of GHG Emissions in A/R CDM Project Activities*[2]
- *TOOL24 Methodological Tool: Common Practice*
- *A/R Methodological Tool: Tool for the Identification of Degraded or Degrading Lands for Consideration in Implementing CDM A/R Project Activities*[3]
- *TOOL16 Methodological Tool: Project and Leakage Emissions from Biomass*

3 DEFINITIONS

In addition to the definitions set out in the VCS document *Program Definitions*, the following definitions apply to this methodology.

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

Baseline control site
Defined area that is managed according to pre-project (baseline) practices (as set out in the schedule of activities) for direct measurement of baseline soil organic carbon stock change. It is linked to and representative of the land in one or more quantification units. Baseline control sites may be within or outside of the project area.

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 (see definition below).

Improved agricultural land management practice
An agricultural practice yielding increased soil organic carbon storage or other climate benefit, involving a refinement to fertilizer or other soil amendment application, water management/irrigation, tillage, residue management, crop planting and harvesting, and/or grazing practices. Projects may implement a single practice or a combined (stacked) practice on each field or land part of their project.

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[2] This tool was deactivated by the CDM as it is no longer required due to methodology improvements (see CDM Executive Board Meeting Report 68 from 16–20 July 2012). There were no technical concerns with the procedures described in the tool; therefore, it is still valid in the context of *VM0042*.

[3] This tool was deactivated by the CDM as it is no longer required as a standalone document (see CDM Executive Board Meeting Report 75 from 30 September–4 October 2013). There were no technical concerns with the procedures described in the tool; therefore, it is still valid in the context of *VM0042*.

Inelastic neutron scattering (INS)

An in-field (in situ) measurement technique based on the detection and analysis of gamma rays emitted by soil elements after irradiation with neutrons. It is also known as neutron-stimulated gamma ray analysis or spectroscopy.

Infrared spectroscopy

Mid-infrared (MIR), near-infrared (NIR), and visible near-infrared (Vis-NIR) spectroscopy, including diffuse reflectance spectroscopy (DRS) and diffuse reflectance infrared Fourier transform spectroscopy (DRIFT). Vis-NIR combines the visible and near-infrared electromagnetic range and usually refers to a wavelength range from 350 to 2500 nm (visible range is between 350 and 700 nm). MIR covers the range between 4000 cm^{-1} and 600 (or 400) cm^{-1}, depending on the instrument.

Laser-induced breakdown spectroscopy (LIBS)

Application of a high-energy pulse to soil samples to generate a high-temperature plasma, which emits radiation at different wavelengths depending on the elements present in the sample

Nitrogen-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, compost, and biosolids

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) in which model application has been validated (see *VCS Module VMD0053 Model Calibration, Validation, and Uncertainty Guidance for Improved Agricultural Land Management*)

Sample point

Sample location of undefined area

Quantification unit

Defined area within the project for which GHG emission reductions and carbon dioxide removals (reductions and removals) are estimated using the selected quantification approach.

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 determined following the data requirements given in Box 1.

Stratum

A subset of each quantification unit within which the value of a variable, and the processes leading to change in that variable, are relatively homogenous.

Synthetic nitrogen fertilizer

Any fertilizer made by chemical synthesis (solid, liquid, gaseous) and containing nitrogen. 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, excluding cultivated annual species with lignified tissues, such as cotton or hemp

4 APPLICABILITY CONDITIONS

This methodology applies to a broad range of project activities that increase SOC storage and/or decrease net emissions of CO_2, CH_4, and N_2O from ALM operations compared to the baseline scenario. The methodology is globally applicable.

This methodology is applicable under the following conditions:

1) Projects introduce or implement one or more new changes to pre-existing ALM practices which:
    a) Improve fertilizer (organic or inorganic) management;
    b) Improve water management/irrigation;
    c) Reduce tillage/improve residue management;
    d) Improve crop planting and harvesting (e.g., improved agroforestry, crop rotations, cover crops); and/or
    e) Improve grazing practices.

    Appendix 1 provides a non-exhaustive list of eligible ALM practices. A change in practice constitutes adoption of a new practice, cessation of a pre-existing practice, or adjustment to a pre-existing practice that results in reductions or removals.

2) Projects introduce or implement quantitative adjustments (e.g., decrease in fertilizer application rate) that exceed 5% of the pre-existing value, calculated as the average value over the historical look-back period, developed for the baseline schedule of

activities (see Section 6). Appendix 1 gives additional details and guidance on practices and on determining practice change.

3) Project activities are implemented on land that is either cropland or grassland at the project start date. The land must remain cropland or grassland throughout the project lifetime except under the following scenarios:
    a) Introduction of temporary grassland into cropland where it is demonstrated, prior to the project start date and to the addition of new project activity instances, that the integration of forage crops (e.g., annual/perennial grasses, legumes) into annual crops is part of a planned, long-term ALM system (e.g., integrated crop-livestock system). 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
    b) A one-time conversion from grassland to cropland or vice versa where it is demonstrated, prior to project validation, that project lands in the baseline scenario are degraded and the introduction of improved land use change practices would significantly improve soil health. Project proponents 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 for procedures on how to propose this type of land use change.
4) Empirical or process-based models used to estimate stock change/emissions via Quantification Approach 1 are:
    a) Publicly available, though not necessarily free of charge,[4] 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. The project proponent must include the model source in the project description (e.g., hyperlink to the model and date of webpage access or citation of peer-reviewed publication). 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 SOC and trace gas emissions resulting from the changes in ALM practices included in the project description;
    c) Able to support repetition of the project model simulations. This includes clear versioning of the model used in the project and stable software support, 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, clearly identify the sources of varying parameter sets and how they were applied to estimate stock change/emissions in the project. Acceptable sources

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[4] It is the responsibility of the project proponent to ensure they have any required licenses for models used in a project.

include peer-reviewed literature and statements from appropriate expert groups that demonstrate evidence of expertise with the model via authorship of peer-reviewed model publications or authorship of reports for entities supporting climate-smart agriculture. These sources must describe the datasets and statistical processes used to set parameter values;

d) Validated per datasets and procedures detailed in Section 5.2 of *VCS Module VMD0053 Model Calibration, Validation, and Uncertainty Guidance for Improved Agricultural Land Management.* Model prediction error must be calculated using datasets as described in Section 5.2.5 of *VMD0053* and must use the same parameters or sets of parameters applied to estimate stock change/emissions in the project; and

e) Using the same model version in the baseline and project scenarios. Further, the same parameters/parameter sets must be used in the baseline and project scenarios. Model input data must be derived following guidance in Table 6~~Table 6~~ and Table 8~~Table 8~~. Model uncertainty must be quantified following guidance in Section 8.6.

This methodology is not applicable under the following conditions:

5) The project area has been cleared of native ecosystems within the 10-year period immediately prior to the project start date.
6) The project activity is expected to cause a sustained reduction in productivity of greater than 5%, as demonstrated by peer-reviewed and/or published studies on activity in the region or a comparable region.
7) The project activity is biochar application. Biochar may be applied as a soil amendment in the project area provided that the total organic carbon content[5] of the biochar applied is subtracted from the estimated SOC stock change in the project scenario at each verification event.
8) The project activities occur on a wetland; this condition does not exclude crops subject to artificial flooding where it is demonstrated that crop cultivation does not impact the hydrology of any nearby wetlands.

5 PROJECT BOUNDARY

The spatial extent of the project boundary is all lands planning to implement the proposed improved ALM practice(s). Carbon pools included in the project boundary in the baseline and project scenarios are listed in Table 2~~Table 2~~.

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[5] To estimate the total carbon content of the applied biochar, project proponents should follow the procedures set out in Sections 8.2.2.1 or 8.2.2.2 (for high- or low-technology production facilities, respectively) in the most recent version of *VM0044 Methodology for Biochar Utilization in Soil and Non-Soil Applications*. Where the technology production facility type is not known, procedures in the low-technology approach (Section 8.2.2.2) should be followed for conservativeness.

Table 2: Selected carbon pools in the baseline and project scenarios

Source	Included?	Justification/Explanation
Aboveground woody biomass	Yes / Optional	Aboveground woody biomass must be included where project activities significantly reduce the pool compared to the baseline. In all other cases, aboveground woody biomass is an optional pool.
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	Belowground woody biomass may optionally be included where project activities significantly increase the pool compared to the baseline.
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.
Dead wood	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.
SOC	Yes	Major carbon pool affected by project activity that is expected to increase in the project scenario
Wood products	No	Carbon pool is optional for ALM project methodologies and may be excluded from the project boundary.

GHG sources included in the project boundary in the baseline and project scenarios are listed in Table 3~~Table 3~~. Specific carbon pools and GHG sources may be deemed de minimis and need not be accounted for (i.e., value set to zero) where together the omitted decrease in carbon stocks (in carbon pools) or increase in GHG emissions (from GHG sources) amounts to less than 5% of the total GHG benefit generated by the project. This includes sources and pools that cause project and leakage emissions. This and all subsequent references to de minimis demonstration are conducted via application of the CDM *Tool for testing significance of GHG emissions in A/R CDM project activities.*[6] The SOC pool must be included in the project boundary[7] (i.e., it must be monitored as part of a *VM0042* project and is not allowed to be deemed de minimis).

Table 3: GHG sources included in or excluded from the project boundary in the baseline and project scenarios

Source	Gas	Included?	Justification/Explanation

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[6] Since project activities must not result in a sustained reduction in productivity (including animal weight gains) or sustained displacement of any pre-existing productive activity, feedlots are conservatively excluded from the project boundary.

[7] Note that the methodology does not separately account for SOC stock changes resulting from erosion.

SOC	CO_2	Yes	Quantified as stock change in the pool, rather than an emissions source (see Table 2)
Fossil fuel	CO_2	S*	Sources of fossil fuel emissions are vehicles (mobile sources, such as trucks, tractors) and mechanical equipment required by the ALM activity.
Liming	CO_2	S*	Application of limestone or dolomite as soil amelioration may represent a significant source of CO_2.
Soil methanogenesis	CH_4	S*	Anoxic conditions in soils may lead to soil methanogenesis.
Enteric fermentation	CH_4	Yes	Where livestock are present in the project or baseline scenarios, CH_4 emissions from enteric fermentation must be included in the project boundary.
Manure deposition	CH_4	Yes	Where livestock are present in the project or baseline scenarios, CH_4 and N_2O emissions from manure deposition and management must be included in the project boundary.
	N_2O	Yes	
Use of nitrogen fertilizers	N_2O	Yes	Must be included where: • The project area would have been subject to nitrogen fertilization in the baseline scenario; or • Nitrogen fertilization is greater in the with-project scenario relative to the baseline scenario.
Use of nitrogen-fixing species	N_2O	Yes	Where nitrogen-fixing species are planted in the project, N_2O emissions from nitrogen-fixing species must be included in the project boundary.
Biomass burning	CO_2	Excluded	Carbon stock decreases due to burning are accounted as a carbon stock change.
Biomass burning	CH_4	S*	Biomass burning releases CH_4.
	N_2O	S*	Biomass burning releases N_2O.
Woody biomass	CO_2	S*	Quantified as stock change in the pool rather than an emissions source (see Table 2)

S* – Must be included where the project activity significantly increases emissions (i.e., by more than 5%) compared to the baseline scenario and may be included where the project activity reduces emissions compared to the baseline scenario.

6 BASELINE SCENARIO

Considering current market trends, existing government policies and legal requirements, socioeconomic conditions, and technological developments in the agriculture sector, the continuation of pre-project ALM practices is determined to be the most plausible baseline scenario for all projects implementing improved ALM following VM0042, ~~(see~~as further ~~justification~~justified in Appendix 3~~)~~. The justification in Appendix 3 is generally applicable to all projects; project proponents are not required to use the framework of Appendix 3 to justify that the continuation of pre-project ALM practices is the baseline scenario for their project.

For each quantification unit (e.g., for each field), baseline scenario practices are set to match the practices implemented in the historical look-back period, creating an annual schedule of activities to be repeated throughout the first baseline period.[8] Baseline emissions/stock changes are then modeled (Quantification Approach 1) or (for SOC stock change only) directly measured in baseline control sites subject to the annual schedule of activities (Quantification Approach 2). Note that under Quantification Approach 1, direct SOC stock estimates are also required at time $t = 0$ years to serve as model input for model initialization.[9] The crops and practices assumed in the baseline scenario must be reassessed every ten years in accordance with the requirements of the most recent version of the *VCS Standard* and revised, where necessary, to reflect current agricultural production in the region.[10] However, where regional production practices change and/or data becomes available across shorter timeframes, it is recommended to reassess the baseline every five years.

Project proponents must describe the baseline scenario for the project area by specifying whether the land is either cropland or grassland at the project start date and providing a comprehensive qualitative description of pre-project ALM practices, covering the categories listed in Table 4. The range of variations observed in all initial project activity instances within the project area must be described.

Project proponents must also identify the specific baseline practices that will be impacted by implementation of the proposed project activity or activities.

For grouped projects, the baseline scenario must be described for each eligibility area.[11a] All observed qualitative variations in the specifications of each ALM practice within each eligibility area must be described. Different land classifications as cropland or grassland must be treated as separate eligibility areas as these reflect distinct baseline conditions.

At future verifications, additional project activity instances may be enrolled. Such instances may exhibit different pre-project ALM practices, provided that at least one of the pre-project ALM practices impacted by project activities in the new instance matches the validated baseline scenario.

Box 2 provides an example of how to describe the baseline scenario of a grouped project in the project description, and how to determine eligibility of new project activity instances joining the eligibility area after validation, based on a hypothetical project.

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[8] For example, where the schedule of activities includes tillage events in years $t = -3$ and -1 but does not involve tillage in year $t = -2$, the schedule of activities for tillage in the baseline scenario would be tillage, no tillage, tillage. This pattern would be repeated as follows for the first baseline period: tillage, no tillage, tillage, tillage, no tillage, tillage, tillage, no tillage, tillage, tillage.

[9] Per Table 6~~Table 6~~, baseline SOC stocks may be (back-)modeled to $t = 0$ from measurements collected within ±5 years of $t = 0$.

[10] See Section 3.2.7 of the *VCS Standard*, *v4.7*.

[11a] Or geographic area per *VCS Standard, v4.7* and previous versions

Box 2: Example of baseline scenario description and eligibility of new project activity instances for a grouped project

A hypothetical grouped project is implemented on cropland among smallholder farmers in the Ethiopian highlands. The proposed project activities are:

1) introduction of legume intercropping (e.g., maize intercropped with common bean or pigeon pea),
2) implementation of no-tillage to improve soil organic carbon and productivity, and
3) implementation of integrated soil fertility management (ISFM) encompassing judicious use of mineral and synthetic fertilizers, and liming every four years.

The baseline scenario is described in the project description as shown in Table B2, covering the specifications listed in Table 4.

Table B2. Baseline scenario description for eligibility area 1 (EA1) – cropland, to be included in project description

Pre-project ALM practice	Qualitative description	Project activity impact
Crop planting and harvesting	Annual food crops (e.g., maize, sorghum, millet). Cereal–cereal or cereal–legume rotation. Minimal soil cover following harvest; no systematic cover cropping.	Yes. Project activity introduces intercropping leguminous cover crops (project activity 1).
Nitrogen fertilizer application	Very low or no mineral and synthetic fertilizer; occasional use of farmyard manure	Yes. Project activity introduces ISFM (project activity 3).
Tillage and residue management	Manual or animal drawn conventional tillage or reduced tillage (e.g., disk tillage) prior to planting. Crop residues partially retained or removed for use as cooking fuel.	Yes. Project activity implements no-tillage (project activity 2).
Water management / irrigation	None (rainfed systems)	No
Grazing practices	Post-harvest free grazing of household livestock (cattle, sheep, goats)	No
Liming	None	Yes. Project activity applies lime every four years (project activity 3).

New project activity instances may be added to EA1 in this hypothetical project when at least one pre-project ALM practice impacted by project activities aligns with the validated baseline scenario, and the land is cropland.

The following project activity instances would be eligible for inclusion in EA1 despite differences to the validated baseline scenario practices (marked in **bold**):

a) Annual food crops (e.g., maize, sorghum, millet). Cereal–cereal or cereal–legume rotation. Minimal soil cover following harvest; no systematic cover cropping. No mineral and synthetic fertilizer; occasional use of farmyard manure. **Strip tillage**. Crop residues removed. Rainfed. Post-harvest free grazing. No liming.
Eligible for inclusion in EA1 as all project activities are planned for implementation.

b) Annual food crops (e.g., maize, sorghum, millet). Cereal–cereal or cereal–legume rotation. Minimal soil cover following harvest; no systematic cover cropping. Low NPK application rates; occasional use of farmyard manure. Animal-drawn conventional tillage. Crop residues removed. **Traditional furrow irrigation**. Post-harvest free grazing. No liming.
Eligible for inclusion in EA1 as all project activities are planned for implementation.

c) Annual food crops (e.g., maize, sorghum, millet). Cereal–cereal or cereal–legume rotation. Minimal soil cover following harvest; no systematic cover cropping. No mineral and synthetic fertilizer; occasional use of farmyard manure. **Strip tillage**. Crop residues removed. Rainfed. Post-harvest free grazing. **Liming every six years**.
Eligible for inclusion in EA1 as project activities 1 (legume intercropping) and 2 (no-tillage) are planned for implementation.

The following project activity instances would not be eligible for inclusion in EA1, because of differences to the validated baseline scenario practices (marked in **bold**):

d) Rotation of **maize intercropped with common bean**, barley, and vetch for controlled grazing. **ISFM. No tillage.** Crop residues retained. Rainfed. **Liming every 3–5 years**.
Not eligible for inclusion in EA1 as all project activities are already part of pre-project practices.

e) Communal **grazing land**. No mineral and synthetic fertilizer. No tillage. Rainfed. Post-harvest free grazing. Continuous grazing dominated by cattle with limited mowing. No liming.
Not eligible for inclusion in EA1 as the land is grassland at the project start date.

Development of Schedule of Activities ~~in the Baseline Scenario~~

For each quantification unit, a schedule of activities ~~in the baseline scenario~~ is determined by assessment of practices implemented during the period prior to the project start date. This forms the basis for calculating baseline emissions following the guidance in Section 8. The interval over which practices are assessed, *x* years, must be a minimum of three years and must include at least one complete crop rotation, where applicable. Where a crop rotation is not implemented in the baseline, $x \geq 3$ years. **For each year, $t = -1$ to $t = -x$ (i.e., years preceding project start), information on ALM practices must be determined, per the requirements presented in** Table 4~~Table 4~~.

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 requires quantitative information related to that practice.

The schedule of activities, beginning with year $t = -x$, is applied in the baseline scenario, from $t = 1$ onward, repeating every *x* years through the end of the first baseline period.

The schedule of activities in the baseline scenario is valid until baseline reassessment. At the end of each baseline period, production of the commercial crop(s) in the baseline scenario is re-evaluated. Published regional (sub-national) agricultural production data from within the five years immediately 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 ALM practices in the region, the baseline scenario is valid as-is, 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 ALM activities (evaluated against common practices in the region) is developed based on written recommendations for the sample field provided by independent professional agronomists, agricultural experts such as soil scientists, husbandry specialists, and agronomists, or representatives of a governmental agricultural body, including government agricultural extension agents. Recommendations must provide sufficient detail to produce the minimum specifications on ALM practices for the baseline scenario as outlined in

- Table 4~~Table 4~~.
- 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 conservativeness must be applied, selecting the value that results in the lowest expected emissions (or highest rate of stock change) in the baseline scenario.
- Where evidence is not field-specific, conservatively derived field-specific values must be supported by a documented method justifying the appropriateness of selection.

Table 4: Minimum specifications for ALM practices in the baseline scenario

ALM Practice	Qualitative	Quantitative
Crop Planting and Harvesting	• Crop type(s) (e.g., crop functional group(s)) • Crop rotation (Y/N) • Cover crops (Y/N) • Intercropping (Y/N)	• 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 N 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 (Y/N)	• Depth of tillage (where applicable) • Frequency of tillage (where applicable) • Percent of soil area disturbed (where applicable) • Percent of crop residue removed (where applicable)
Water Management/Irrigation	• Irrigation (Y/N) • Flooding (Y/N)	• Irrigation rate (where applicable)
Grazing Practices	• Grazing (Y/N) • Animal type (where applicable) • Harvesting/mowing (Y/N)	• Animal stocking rate (i.e., number of animals and length of time grazing in each area annually, where applicable) • Frequency of harvest
Liming	• Application of calcitic limestone or dolomite (Y/N)	• Calcitic limestone or dolomite application rate (where applicable)

*Y/N: Yes/No

Box 1: Sources of qualitative and quantitative data

Sources of information for all undefined activity/management-related model input variables (see Table 6~~Table 6~~ and Table 8), and all parameters relevant to the baseline scenario (i.e., all parameters with the subscript *bsl* that reference Box 1 in its respective parameter table), must follow the requirements detailed below.

All qualitative information on ALM practices must 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 must follow the quantitative information hierarchy outlined below.

The following list specifies the allowable sources of quantitative information on ALM practices in descending order of preference, as available:

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 ALM 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 conservativeness must be applied and the value that results in the lowest expected emissions (or highest rate of stock change) in the baseline scenario must be selected.
3) A signed attestation from the farmer or landowner of the sample field during that period – where 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 on application rates in that area, or statement from a local extension agent regarding local application rates). The VVB must determine whether the data are sufficient. In circumstances where this requirement is not 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. Where estimates have been disaggregated by relevant crop or ownership classes, those should be used. The estimates must be substantiated with a signed attestation from the farmer or landowner of the sample field during that period. Examples include the USDA National Agricultural Statistics Service Quick Stats database and USDA Agricultural Resource Management Survey.

This hierarchy applies to any additional quantitative inputs required by the model (Quantification Approaches 1 and 2) or default factor (Quantification Approach 3) selected. The principle of

7 ADDITIONALITY

This methodology uses a project method for the demonstration of additionality. For grouped projects, demonstration of additionality must be based upon the initial project activity instances (see further details in the most recent version of the *VCS Standard*). Project proponents using this methodology must:

1) demonstrate regulatory surplus;
2) identify institutional barriers that would prevent the implementation of a change in pre-existing ALM practices; and
3) demonstrate that adoption of proposed individual or combined project activities is not common practice.

Further details on each of these steps are provided below.

Step 1: Regulatory surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements set out in the most recent version of the *VCS Standard*.

Step 2: Barrier analysis

Project proponents must apply the procedures and requirements in Step 2 of the most recent version of *VT0008 Additionality Assessment*.

For the purposes of this methodology, Step 2 of VT0008 must only be applied with respect to the project activity. Sub-steps that require assessment of the alternative scenarios described in Appendix 3 in this methodology need not be applied.

When applying Requirement 1 in Appendix 1 of VT0008, project proponents must provide publicly available, transparent, and verifiable evidence relevant to the project area and the proposed project activities, such as:

1) agricultural census or other government (e.g., survey) data;
2) peer-reviewed scientific literature;
3) independent reports, assessments, or datasets issued by recognized international institutions or multilateral organizations (e.g., the World Bank, FAO, WBCSD);
4) independent research data (i.e., empirical data or analyses produced by universities, public research institutes, or non profit research organizations using documented and reproducible methods), where the data provider has no direct financial, operational, or governance relationship with the project entity; or
5) reports or assessments compiled by industry associations.

Step 3: Demonstrate that adoption of proposed individual or combined project activities is not common practice

Project proponents must determine whether the proposed project is common practice in each region (or 'geographic area' as defined for grouped projects in the *VCS Standard*) included within the project area. A project region for demonstrating common practice must be defined by stratifying the project area to the state or provincial level (or equivalent second-order jurisdiction) in the countries where the project is being developed. For grouped projects, the region to be considered is the "geographic area" (*VCS Standard, v4.7* and previous versions) or "eligibility area" (*VCS Standard, v5.0*).

Common practice is defined as greater than 20% adoption.[12] The approach to common practice demonstration outlined in this section follows a two-step process: 1) determine if the project activity has below 20% adoption in the project region, and 2) where the adoption rate is greater than 20% or the required data is not available, project proponents must demonstrate that the activity is not common practice by applying Step 4c of *VT0008*.

The proposed project activity may be implemented as an individual practice (e.g., cessation of tillage) or a combined practice (e.g., conservation agriculture encompassing no-tillage, crop rotations and residue retention). Such combined practices are defined as those implemented on the same field/management unit in the same baseline crop rotation cycle or for at least three years where a crop rotation is not implemented (i.e., aligned with Section 6).

Step 3.1: To determine that an individual or a combined practice is not common practice, the adoption rate of the respective individual practice or combined practice must be demonstrated to be lower than 20% where the practices are implemented.

Evidence of practice adoption rates within the project area must be provided in the form of publicly available information contained in:

a) agricultural census or other government (e.g., survey) data;

b) peer-reviewed scientific literature;

c) independent research data; or

d) reports or assessments compiled by industry associations.

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[12] Twenty percent is the precedent for a common practice threshold established in Section 18 of the CDM *Methodological tool: Common practice*. Available at: https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-24-v1.pdf

Mathur et al. (2007) and Barnes et al. (2014) confirm that approximately 20% is an appropriate threshold for common practice based on analysis of technology adoption and market penetration using different approaches.

To demonstrate common practice, the project area must be stratified to the state or provincial level (or equivalent second-order jurisdiction) in the countries where the project is being developed. Where supporting evidence is unavailable at the state/provincial level (e.g., in developing countries), aggregated data or evidence at a subnational, national, or regional level may be used with justification. Where stratification based on geopolitical boundaries is impractical (e.g., due to lack of data), other forms of stratification, such as major soil types or cropping zones, may be used with justification. The same stratification approach and data sources must be applied across the entire project to maintain the integrity of the common practice demonstration. The common practice assessment data source selected must be justified to be appropriate for the stratified project area.

Where evidence for a proposed project activity in the region is not available from any of these sources, the project proponent may obtain a signed and dated attestation statement from a qualified independent local expert (e.g., agricultural extension agent, accredited agronomist) estimating the adoption rate. All projects using independent local expert attestation must provide the qualifications of the expert and the methods used to inform their analysis. It is recommended that the contracted expert has professional indemnity insurance.

Step 3.2: Where the best available data from the above sources for an individual or combined practice determines that the adoption rate is greater than 20% or the required data is not available, project proponents must demonstrate that the activity is not common practice by applying Step 4c of *VT0008*. This step involves identifying essential distinctions between the proposed project activity (i.e., an individual or combined practice) and ~~related~~ similar activities that ~~may be captured under~~per Step 3.1 show an adoption rate higher than 20%. When applying Step 4c of *VT0008*, the information sources for N_{all} and N_{diff} must cover the same ~~geographic area (i.e., the~~ project region as defined in the introductory paragraph to Step 3[13a].~~),~~ ~~and t~~ The analysis must be based on ~~a~~the land area ~~basis~~ (e.g., hectares). The requirement that $N_{all} - N_{diff}$ must be greater than 3 is not applicable.

For example, a project intends to introduce cover crops as a project activity in the project region where the adoption rate per the government agricultural census is 22% covering approximately 2 million hectares (N_{all}). Applying the common practice analysis per Step 4c of *VT0008*, the project identifies the following essential distinction: government subsidies for cover crop seed are accessed by farmers managing 1.7 million hectares (N_{diff}) in the project region. The calculation of factor F ($F = 1 - N_{diff} / N_{all}$) per Step 4c of *VT0008* would therefore yield 15% ($F = 1 - 1.7$ million hectares / 2 million hectares $= 0.15$), demonstrating that the proposed project activity is not considered common practice.

[13a] The requirements of Section 5.1 of VT0008 to determine an 'applicable geographic area' do not apply.

8 QUANTIFICATION OF REDUCTIONS AND REMOVALS

8.1 Summary

This methodology provides a flexible approach to quantifying reductions and removals from the adoption of improved ALM practices in the project compared to the baseline scenario. Baseline and project emissions are defined in terms of flux of CH_4, N_2O, and CO_2 in tonnes of CO_2e per unit area[14] per verification period. Within each quantification unit, stock and emission changes in each included pool or flux are treated on a per unit area basis in accounting procedures. Section 8.5 provides equations using total stock or emission changes in the project to quantify net reductions and removals. Where a verification period spans multiple calendar years, the equations quantify reductions and removals by year to appropriately define vintage periods.

The entire project area is divided into multiple quantification units that must be demonstrated to be more homogenous than the project area in its entirety, for the purposes of estimating emission reductions and removals (ERRs) (i.e., similar management activities, soil type, climate). In some cases, the entire project area may be considered as one quantification unit. When dividing the project area into multiple quantification units, ~~E~~estimates of ERRs for each quantification unit within the project area are then aggregated to produce an estimate for the entire project area. In a staged (i.e., hierarchical, nested) design, additional units nested within a primary quantification unit may be implemented resulting in primary, secondary, tertiary, etc. quantification units (see Appendix 6 for an example). Quantification units must be clearly defined in the description of the sampling design provided in the project description~~ document~~.

In grouped projects, the determination of different eligibility areas[15a] may be treated independently from potential division into quantification units. Thus, quantification units may span across multiple eligibility areas or represent subdivisions of one eligibility area.

The approaches for quantifying CO_2, CH_4, and N_2O emissions are listed in Table 5~~Table 5~~. Where more than one quantification approach is allowable for a given gas and source, more than one approach may be used provided that the same approach is used for a given quantification unit in both the project and baseline scenarios.

Table 5: Summary of allowable quantification approaches

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[14] Note that for reporting purposes, hectares should be used as the unit area when applying this methodology.

[15a] Geographic area per *VCS Standard, v4.7* and previous versions

GHG/ Pool	Source	Quantification Approach 1: Measure and Model*	Quantification Approach 2: Measure and Remeasure	Quantification Approach 3: Default Factors
CO_2	SOC	X	X	
	Fossil fuel			X
	Liming			X
	Woody biomass**			
CH_4	Soil methanogenesis***	X		
	Enteric fermentation			X
	Manure deposition			X
	Biomass burning			X
N_2O	Use of nitrogen fertilizers***	X		X
	Use of nitrogen-fixing species***	X		X
	Manure deposition***	X		X
	Biomass burning			X

* Approach 1 may only be used where a valid model is available (see model requirements in *VMD0053*).

** Where included in the project boundary, woody biomass 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.* Where woody biomass is harvested, project proponents must calculate the long-term average GHG benefit following guidance in the most recent versions of the *VCS Methodology Requirements*,[16] and the *VCS Standard*.[17]

*** Measured data on CH_4 and N_2O fluxes as described in VMD0053, v2.0 are required for model calibration and validation when following Quantification Approach 1. Periodic measurements of CH4 and N2O fluxes as part of project monitoring is not required.

For each pool/source, subdivisions of the project area using different quantification approaches must be stratified and accounted separately. A project may switch between allowable quantification approaches for a given source during the project lifetime, provided that the same approach is used for both the project and baseline scenarios. The quantification approaches are as follows.

Quantification Approach 1: Measure and Model

An acceptable model is used to estimate GHG flux based on soil characteristics, implemented ALM practices, measured initial SOC stocks, and climatic conditions in quantification units. Measurements of SOC stocks are required every five years or more frequently (see Table 8~~Table 8~~). The remeasurement data is used to re-estimate model prediction error and recalibrate the model (i.e., “true-up”, see Section 8.6.1.3).

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[16] See Section 3.6.6 in the *VCS Methodology Requirements, v4.4*

[17] See Sections 3.2.28-3.2.30 of the *VCS Standard, v4.7*

Neither initial nor periodic measurements of CH_4 and N_2O fluxes are required as part of project monitoring. High-quality observed experimental data on soil CH_4 and N_2O emissions from controlled research trials or approved data sources as described in VMD0053 are required for model calibration (see Section 5.1 of VMD0053 and validation (see Section 5.2.3 of VMD0053. Measured datasets must be drawn from peer-reviewed and published experimental datasets with measurements of N_2O and CH_4 fluxes, ideally using control plots to test the practice change. Datasets may also be drawn from a benchmark database maintained by a third party or from measurements made within the project boundary, where approved by the independent modeling expert (IME),see Appendix 1 of VMD0053.

Quantification Approach 2: Measure and Remeasure

Direct measurement is used to quantify changes in SOC stocks. This approach is relevant where models are unavailable or have not yet been validated or parameterized, or where project proponents prefer to use a direct measurement approach for SOC stock change. The baseline scenario is measured and remeasured directly at a baseline control site linked to one or more quantification units. Quantification Approach 2 is only applicable to SOC.

Quantification Approach 3: Default Factors

GHG flux is calculated following the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* using equations contained in this methodology.

Where a given activity is not practiced in the baseline or project scenarios, resulting in an effective input of zero for any equation element in this methodology, that equation element is not required.

Baseline and project emissions are calculated for each sample field using applicable default values and any monitored parameters. The most accurate available emission factor applicable to the project conditions must be used, in the following descending order of preference:

1) Where available, a project-specific emission factor from a peer-reviewed scientific publication[18] must be used.
2) Where there is no relevant peer-reviewed scientific literature, the project proponent may propose alternative sources of information (e.g., government databases, industry publications) to establish the default factor(s) and must provide evidence that the

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[18] As stated in Section 2.5.2 of the latest version of the VCS Methodology Requirements, peer-reviewed scientific literature used to derive (default) emission factors must be in a journal indexed in the Web of Science: Science Citation Index.

alternative source of information is robust and credible (e.g., independent expert attestation).

3) Where no alternative information source is available that is applicable to the project conditions, projects may derive emission factors using activity data collected during the project by following the guidance to derive Tier 2 emission factors in the respective sections of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

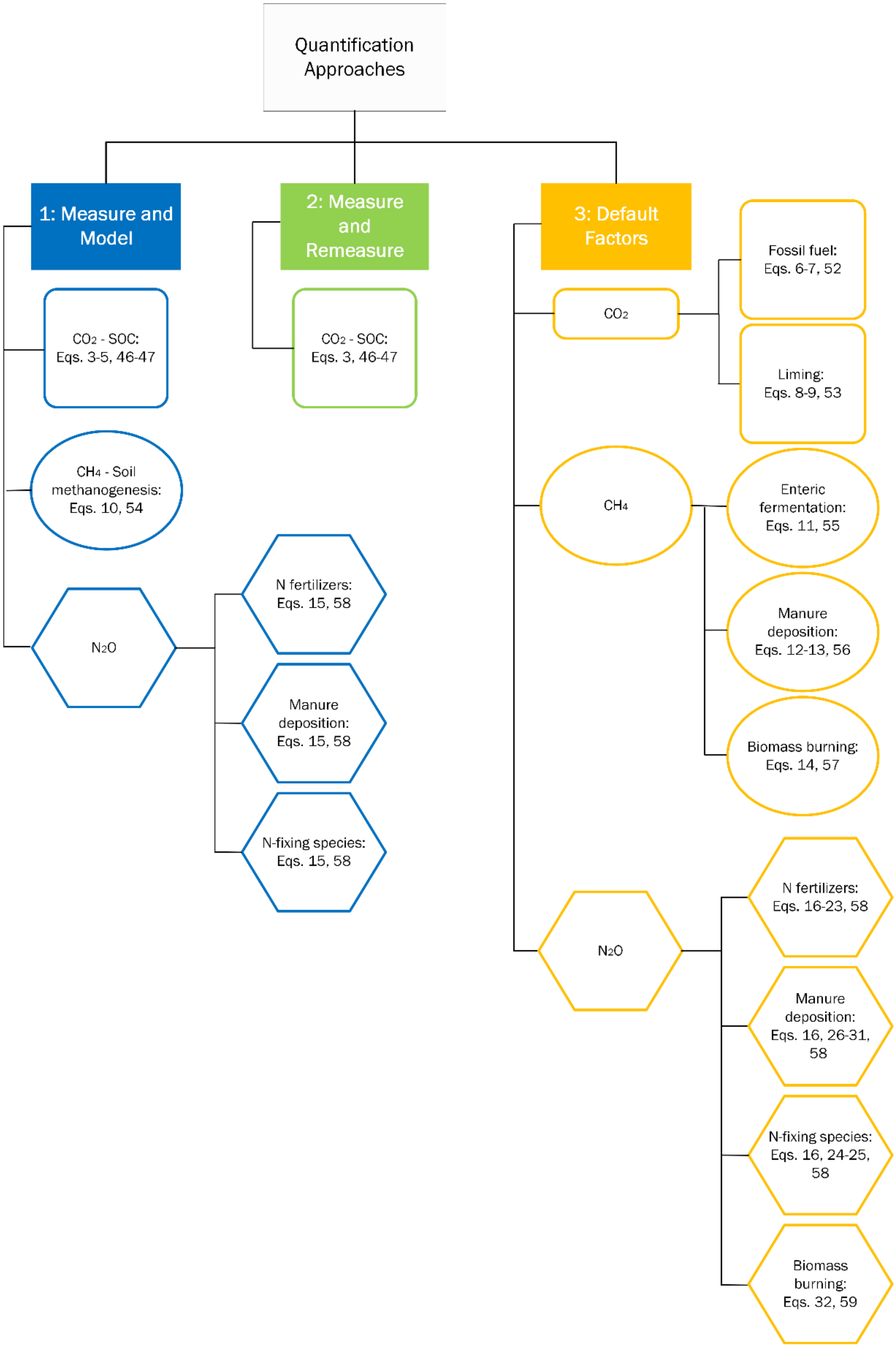
4) Where projects justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a emission factors from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories may be selected.

Summary

Figure 1 summarizes which equations are to be applied to each GHG flux depending on the selected quantification approach (see also Table 5~~Table 5~~).

Project proponents must use the templates available on the *VM0042* webpage to prepare the documents required for project validation and verification, including the templates for ERR quantification spreadsheet, model validation report and IME assessment report.

Figure 1: Equation map of this methodology



Woody biomass must be quantified as per Table 5~~Table 5~~ 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*, and reported using Equations (48)~~(48)~~ and (49)~~(49)~~. Where woody biomass is harvested, projects must calculate the long-term average GHG benefit following guidance in the most recent versions of the *VCS Methodology Requirements*, Section 3.6 and the *VCS Standard*, Section 3.2.

8.2 Baseline Emissions

Quantification Approach 1

The baseline is modeled for each quantification unit. The model serves to project future stock change/emissions resulting from the schedule of ALM activities taking place in the baseline scenario (derived in Section 6). Further guidance on biophysical model inputs is elaborated in Table 6~~Table 6~~.

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

Model Input Category	Timing	Approach
SOC content to calculate SOC stocks (initial)	Determined prior to project intervention via direct measurements at t = 0 or (back-) modeled to t = 0 from measurements collected within ±5 years of t = 0	Directly measured via conventional analytical laboratory methods (e.g., dry combustion) or proximal sensing techniques (e.g., INS, LIBS, MIR, and Vis-NIR) with known uncertainty following the criteria in Appendix 4 at t = 0 or (back-) modeled to t = 0 following *VMD0053* guidance. See parameter table for $\overline{SOC_{bsl,i,t}}$.
Bulk density to calculate SOC stocks (initial)	Determined prior to project intervention via direct measurements at t = 0 or from measurements collected within ±5 years of t = 0	See Section 8.2.1.5
Soil properties (other than bulk density and SOC)	Determined prior to project intervention	Directly measured or determined from published soil maps with known uncertainty. Estimates from direct measurements must: • Be derived from representative (unbiased) sampling; and • Ensure accuracy of measurements through adherence to best practices.

Climate variables (e.g., precipitation, temperature)	Continuously monitored ex post	Measured for each model-specific meteorological input variable at its required temporal frequency (e.g., daily) for the model prediction interval. Measurements are taken at the closest continuously monitored weather station not exceeding 50 km from the sample field, or from a synthetic weather station (e.g., PRISM[19]).

Quantification Approach 2

Baseline SOC stocks are measured and remeasured directly at baseline control sites which are linked to quantification units. Control sites are managed by applying schedules of activities established in the baseline scenario for the corresponding quantification unit (derived in Section 6). Control sites must comply with the similarity criteria listed in Table 7~~Table 7~~ and be within 250 km of their linked quantification units. One control site may be linked to more than one quantification unit provided the control site meets the similarity criteria for each quantification unit to which it is linked.

Control sites may be managed by project proponents, implementing partners, or by entities external to the project (e.g., experimental research stations outside of the project area). Management of control sites may change during the project but the location of baseline control sites themselves must remain constant over the project lifetime. Control sites must be sufficiently large to ensure that any changes in SOC stocks are driven by baseline management practices (i.e., edge effects must be eliminated) and to allow for baseline practices to continue unimpeded (e.g., tractors, combines, or other equipment must be able to operate as they would under normal conditions). Where adverse conditions such as extreme weather events or pest outbreaks arise during the project crediting period, managers of control sites may deviate from the schedule of activities to mitigate negative impacts as they would in the absence of a carbon project (e.g., halt irrigation if there is excess rainfall).

Under this approach at least three control sites are required across the entire project area, but more will decrease uncertainty, particularly where the total number of control sites is less than ten. Note that with increasing variability and heterogeneity of the project area, a higher number of control sites is necessary to ensure that similarity criteria are met. Since stratified random sampling is the required sampling strategy for this methodology (see Section 8.2.1), there must be at least one control site per stratum, or the control site must be divided into the same strata as the corresponding quantification unit. Baseline SOC stocks must be reported for the baseline control sites and for each stratum within the project area. See Section 8.6.2 as well as the *Soil Organic Carbon MRV Sourcebook for Agricultural Landscapes*[20] for further information on the number of samples to collect.

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[19] Available at: https://climatedataguide.ucar.edu/climate-data/prism-high-resolution-spatial-climate-data-united-states-maxmin-temp-dewpoint

[20] Box 3.5. Available at: https://openknowledge.worldbank.org/handle/10986/35923

Table 7: Similarity criteria for linking baseline control sites to quantification units under Quantification Approach 2

Control Site Similarity Criterion	Threshold[a]
Topography	Most frequent slope class[21] must be the same in the quantification units and control sites (to be determined from a slope map or via a GIS slope analysis[22]). For control sites classified as hilly, steep, or very steep, the aspect must be within 30° of the cardinal direction of the linked quantification unit.
Soil texture to depth of project boundary (minimum 30 cm)	Average soil texture must be in the same FAO[23] soil textural class as the average soil texture of the linked quantification unit. Note that where significant textural differences are evident within 0–30 cm depth, texture should be determined separately for the different soil horizons within that depth range.
Soil group	Soil group must be within the same reference soil group, according to the FAO *World Reference Base for Soil Resources,*[24] as the linked quantification unit.
Average SOC percent by dry weight to depth of project boundary (minimum 30 cm)	The percentage must not be significantly different from the mean percentage SOC of the linked quantification unit at a 90% confidence level.
Historical ALM activities	Historical ALM activities must be the same as in the linked quantification unit for at least five years prior to project start date: • Tillage (Y/N[d]) and type of tillage practice (no tillage, conservation tillage, or conventional (full) tillage) • Crop residue removal (Y/N) • Crop planting and harvesting (crop type[e]) • Manure application (Y/N) • Compost application (Y/N) • Irrigation (Y/N) Note that not all of these activities will be universally relevant to all agricultural systems. Therefore, the project proponent must provide evidence supporting the selected historical ALM activities used to link control sites with quantification units. See Box 1 for guidance on data sources for establishing historical ALM activities.

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[21] See Table 10 in Appendix 5 for soil slope classifications

[22] See Appendix 5 for workflow steps to determine the most frequent slope class using geographical information systems (GIS)

[23] See Annex 4 in the FAO *World Reference Base for Soil Resources 2014* available at: https://www.fao.org/3/i3794en/I3794en.pdf The USDA Soil Texture Calculator (available ab: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167) may be used to determine the soil texture class based on percent sand and clay content.

[24] See Table 2 of the FAO *World Reference Base for Soil Resources 2014*

Control Site Similarity Criterion	Threshold[a]
Historical land cover[b]	For lands converted up to 50 years prior to the project start date, the site must be converted from the same major land cover type (e.g., forestland, grassland, savanna) as the linked quantification unit within ±10 years.
Native vegetation	The site must be within the same terrestrial ecoregion[25] as the linked quantification unit.
Climate zone	The site must be within the same IPCC-defined climate zone as the linked quantification unit.
Precipitation[c]	The site must have mean annual precipitation within ±100 mm of the linked quantification unit.

[a] Estimates of these quantitative thresholds must be derived from unbiased, representative sampling of the control site. Accuracy must be ensured through adherence to best practices (to be determined by the project proponent and outlined in the monitoring plan – see Section 9.3).

[b] Estimated based on historical satellite or aerial imagery or, where imagery is unavailable, confirmed via local expert attestation

[c] Estimated based on measurements taken at the closest continuously monitored weather station not exceeding 50 km from the control site or from a synthetic weather station (e.g., PRISM)

[d] Y/N: Yes/No

[e] Where crop type in the quantification unit of the project area cannot be matched in the baseline control site, a different crop from the same crop functional group may be selected. Crop functional group is defined in VMD0053 as "Broad category of crop species with similar characteristics (e.g., grasses, legumes, non-legume broadleaf species)."

Quantification Approach 3

The baseline is calculated for each sample field using the equations provided. Emissions resulting from the schedule of ALM activities taking place in the baseline scenario (derived in Section 6) are estimated using default emission factors and data are determined for each sample field at validation.

8.2.1 Soil Organic Carbon Stocks

Direct measurements of SOC stocks are required under Quantification Approach 1 as model inputs for baseline setting and at a minimum every five years after for model true-up. Direct measurements of SOC stocks are also required under Quantification Approach 2 to determine the baseline and project SOC stocks at the project start date and at each verification event. The initially measured SOC stocks (at t = 0 determined through direct measurements or (back-) modeled to t = 0 from measurements collected within ±5 years of t = 0) are the same in both the baseline and project scenarios at the outset of the project (i.e., $SOC_{wp,i,0} = SOC_{bsl,i,0}$) when following Quantification Approach 1.

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[25] As defined in the WWF Terrestrial Ecoregions of the World database. Available at: https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world

Soil sampling and modeling should occur on a point or small plot (i.e., composite sample) basis to allow for accurate estimation of sampling error and its contribution to the uncertainty of credit estimates. Points should be allocated within the lowest level quantification units using an acceptable approach. Where small plots or composite samples are used, the distance between points in such a sample should be minimized to improve estimates of spatial variability.

SOC stock estimates generated must:

1) Be demonstrated to be unbiased and derived from representative sampling; and
2) Ensure the accuracy of measurements and procedures through the employment of quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in the monitoring plan).

Measurement procedures for SOC and bulk density must be thoroughly described, including all sample handling, analysis preparation, and analysis techniques. Further details on each of these procedures are provided in the following sections.

8.2.1.1 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 quantification 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, sample locations must be georeferenced[26] and seasonal variability considered.
- 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.

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

8.2.1.2 Sampling Design: Stratified Random Sampling

Soil sampling must be conducted following the stratified random sampling strategy.[27] Each quantification unit within the project area should be divided into sub-units (i.e., strata) based on factors influencing SOC stock distribution (see below) that make each stratum more homogenous than the project area in its entirety.

Each quantification unit within the project area must be divided into homogenous strata based on factors influencing SOC stock distribution. In a staged (i.e., hierarchical, nested) design, strata should be generated at the lowest level of quantification unit (see Appendix 6 for an example). Thus, if a sampling design establishes primary and secondary quantification units, strata should be generated as a subset of each secondary quantification unit. The aim of stratifying each quantification unit is to capture SOC stock variability more accurately. Depending on the size of the agricultural fields or paddocks, strata may span numerous fields/paddocks, or one field/paddock may be divided into several strata.

Figure 2 shows two examples of defining quantification units and strata. 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.[28]

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.

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 quantification units) into

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[27] 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).

[28] See Section 3.20 of the most recent version of the *VCS Standard* for detailed guidance.

strata that are more homogenous than the project area in its entirety, defined by factors that influence SOC stocks (e.g., those listed as similarity criteria for defining baseline control sites in Table 7~~Table 7~~) is expected to 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[29] (e.g., the Harmonized World Soil Database), SoilGrids,[30] 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.

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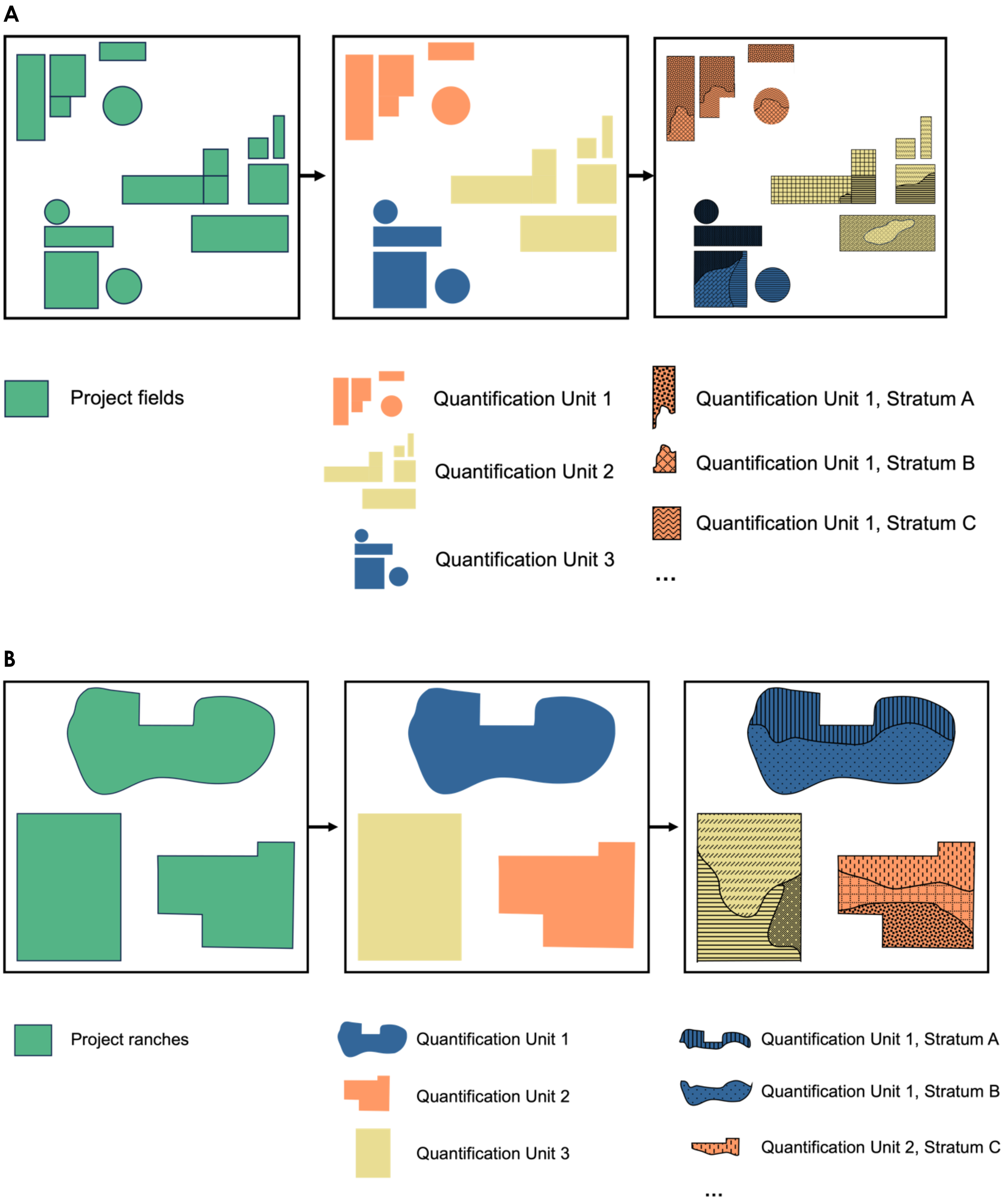
[29] Available at: http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/en/

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

Figure 2: Examples of defined quantification units and strata



8.2.1.3 Collection and Processing of Soil Samples

The following are guidelines for collection and processing 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.[31] Any coarse material must be prevented from passing through a 2 mm sieve. Drying and sieving procedures must follow laboratory-specific standard operating procedures (SOPs) and be consistent for all samples collected as part of the project, and during the entire project lifetime.
5) Soil samples must be shipped within five days of the completion of a sampling campaign. Until then, samples may be temporarily stored on-site in a location protected from sunlight, humidity, and precipitation, avoiding mixing of the different soil materials. Once shipped and before analysis, samples may be stored under environmentally controlled conditions that minimize biological activity (e.g., as dried or refrigerated samples, but not frozen). The duration of refrigerated storage before analysis should not exceed 3 months.
6) Sample processing procedures must be reported in detail, explicitly describing sieving and grinding procedures. These must remain consistent through the entire project lifetime even if there is a change in analytical laboratory.
7) 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 (or down to bedrock/hardpan where soils are shallower than 30 cm). To eliminate

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

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 divided into at least two increments. Soil mass may be derived from bulk density measurements using soil corers.

   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 improved 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 (see columns K and L in Figure 3) are determined (see Section 8.2.1.6). 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.

8) 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. Quantification units with these characteristics must be documented and SOC stocks must only be reported to the sampled depth.[32]

9) 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.

10) 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.

11) A power analysis may be conducted to calculate the number of samples needed to enable accounting of a minimum detectable difference, following Equations (1) and (2) (FAO, 2019). However, projects are not required to take this number of samples.

$$MDD \geq \frac{S}{\sqrt{n}} \times \left(t_{\alpha,\upsilon} + t_{\beta,\upsilon}\right) \tag{1}$$

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[32] This will affect the ESM layers of the respective sampling points shallower than 30 cm (see Section 8.2.1.6).

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

Where:

MDD = Minimum detectable difference

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

n = Number of samples

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 is found in Aynekulu et al. (2011), FAO (2019), de Gruijter et al. (2016), Hengl et al. (2003), ISO (2018, p. 18), Maillard et al. (2017), Mudge et al. (2020), and Vanguelova et al. (2016).

8.2.1.4 Measurements of SOC Content

SOC content with known uncertainty should be measured using dry combustion (Dumas method). In addition, the following proximal sensing techniques are allowed: infrared spectroscopy, including near infrared (NIR), visible near infrared (Vis-NIR), and mid-infrared spectroscopy (MIR); laser-induced breakdown spectroscopy (LIBS); and inelastic neutron scattering (INS, also known as neutron-stimulated gamma ray analysis or spectroscopy). Appendix 4 provides criteria for evaluating the use of IR spectroscopy, LIBS, and INS.

The selection of an analytical laboratory should be based on its listing as an approved analytical service provider of SOC measurements according to national and/or international standards/accreditation. Where possible, the selected analytical laboratory should be ISO/IEC 17025 accredited. All samples throughout the entire project lifetime should be analyzed in the same laboratory. A change of analytical laboratory requires justification. The project proponent must ensure that soil analysis methods and procedures remain consistent even if there is a change of laboratory. Where the project adopts a new eligible method when adopting a new version of the methodology (e.g., a proximal sensing method per Appendix 4), project proponents or their technical service providers must demonstrate the comparability of previous measurements with new remeasurements, and, where necessary, justify the use of conversion factors.

The selected analytical laboratory should quantify and report analytical error statistics (determined by repeated analyses of the same sample) to project proponents on a regular basis. The selected laboratory should provide information on their internal quality control program, for example inclusion of soil reference material with known results, testing documentation according to quality cards (monitoring of variation in analysis, set of error thresholds). Further evidence of analytical quality performance evaluation should be provided by participation in round-robin testing (e.g., through participation in the North American Proficiency Testing program[33]) or registration as a member of the Global Soil Laboratory Network (GLOSOLAN[34]).

Walkley-Black (wet) oxidation and loss on ignition (LOI) are not recommended due to accuracy concerns but may be applied where no other method is available.

The use of remote sensing to estimate and monitor SOC stock changes is allowed through digital soil mapping used to initialize and/or true-up any model under Quantification Approach 1 or used to generate mapped predictions of SOC content and/or stock at different times under Quantification Approach 2. The requirements and procedures of the most recent version of *VT0014 Estimating Organic Carbon Stocks Using Digital Soil Mapping* must be applied.

8.2.1.5 Measurements of Bulk Density

Bulk density must be determined applying the core, excavation, or clod methods in the field, and subsequently processing the samples in the laboratory. Best practice guidance and established standards for these methods, such as *ISO 11272:2017 Soil quality — Determination of dry bulk density*, must be used. Bulk density as soil mass per volume of sampling cores must not include particles greater than 2 mm in diameter (i.e., gravel/stones/rocks/coarse fraction) nor plant material. The coarse fraction may be estimated by sieving and weighing stones/rocks/gravel and multiplying them by the average density of the coarse material.[35]. Beem-Miller et al. (2016) provide a useful approach to ensuring high-quality sampling in rocky agricultural soils. Samples for bulk density, dry soil mass, and SOC content should be taken at the same time and from sampling locations within a few meters of the previous sampling point location, avoiding edge effects and disturbed areas.

8.2.1.6 Calculation of SOC Stocks

To ensure that changes in SOC stocks do not arise solely from a temporal change in bulk density (related to ALM practices), SOC stock changes based on measurements (including for baseline and true-up measurements under Quantification Approach 1) must be calculated on an ESM basis[36] following the procedures explained in Ellert and Bettany (1995), Wendt and Hauser (2013), or von Haden et al. (2020). The SOC mass of each depth layer or increment per unit area is calculated as the product of soil mass and organic carbon concentration, where soil

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[33] See https://www.naptprogram.org/

[34] See https://www.fao.org/global-soil-partnership/glosolan/en/

[35] FAO (2019) provides details on a method to estimate the coarse mineral fraction volume. Although this is a precise method, it is not required under this methodology as it is very time-consuming.

[36] Calibration and statistical validation datasets used for modeling under Quantification Approach 1 do not need to meet the ESM requirement.

mass is obtained by dividing the dry sample mass in each depth layer by the area sampled by the probe or auger (Wendt & Hauser, 2013):

$$M_{n,dl,SOC} = \left(\frac{M_{n,dl,sample}}{\pi \left(\frac{D}{2} \right)^2 \times N} \times 10\,000 \right) \times OC_{n,dl} \tag{3}$$

Where:

$M_{n,dl,SOC}$ = SOC mass in soil sample *n* in depth layer *dl* (kg/ha)
$M_{n,dl,sample}$ = Soil mass of sample *n* in depth layer *dl* (g)
D = Inside diameter of probe or auger (mm)
N = Number of cores sampled (unitless)
$OC_{n,dl}$ = Organic carbon content in sample *n* in depth layer *dl* (g/kg)
10 000 = Conversion factor from g/mm^2 to kg/ha

The cumulative SOC mass per unit area is then calculated by summing all sampled depth increments (see column H in Figure 3). Project proponents may use the spreadsheet[37] provided in Wendt and Hauser (2013) to calculate reference ESMs and adjustments independently from sampled depth increments by using a cubic spline function (see Figure 3). Alternatively, the R script[38] provided in von Haden et al. (2020) may be applied. Where one of these templates is used, a copy showing the calculation procedures must be submitted as part of the documentation to be validated by the validation/verification body (VVB).

In the example in Figure 3, the cumulative organic carbon (OC) mass to 30 cm depth at the first sampling point *VM42point1-1* is 47.36 Mg/ha (t/ha; cell H15) for a cumulative soil mass of 1950 Mg/ha (cell F15). Column I provides standard cumulative reference masses, which in this example have been adjusted to cover the maximum measured soil mass (sample with highest density). The respective ESM layers are set as 0–1950 Mg/ha and 1950–3253 Mg/ha (column L). The values in column M represent the OC mass in each ESM layer, calculated with a cubic spline function. To comply with reporting SOC stocks to at least 30 cm depth on an ESM basis, projects must use the cumulative reference soil mass for 0–1950 Mg/ha. In this example, the three sample points would have SOC mass of 47.36 Mg/ha (cell J15), 49.9 Mg/ha (cell J20), and 36.8 Mg/ha (cell J25). These match the values in column M. These values must then be used to calculate an average SOC mass valid for the total area of the quantification unit. When re-sampling and comparing SOC stocks at two different points in time, the same principle must

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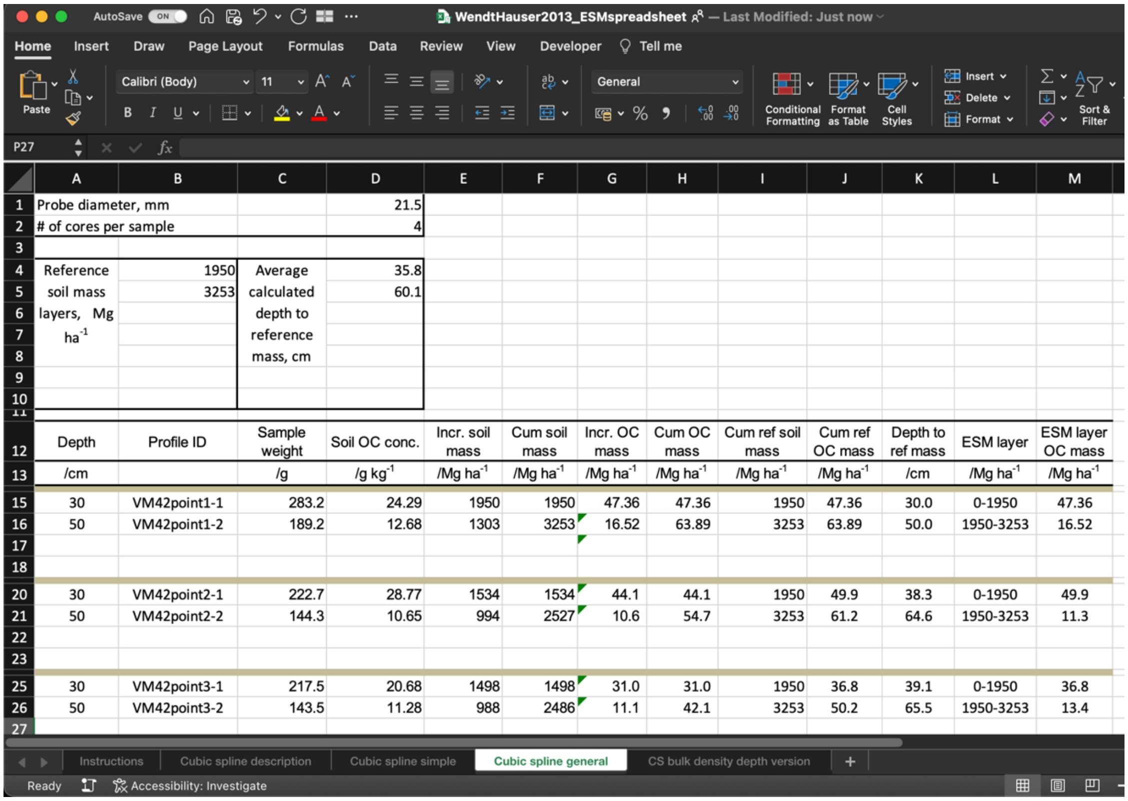
[37] Available for download in the VM0042 webpage at: https://verra.org/wp-content/uploads/2025/01/ESM-sample-spreadsheets-Wendt-and-Hauser-2013.xlsx

[38] Available at: https://onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1111%2Fgcb.15124&file=gcb15124-sup-0002-Supinfo.pdf

be applied to ensure that results are reported for an ESM that covers the measured sample with the highest density (i.e., highest determined soil mass).

Figure 3: Screenshot of ESM spreadsheet provided in Wendt and Hauser (2013)



	A	B	C	D
1	Probe diameter, mm			21.5
2	# of cores per sample			4
3				
4	Reference soil mass layers, Mg ha^{-1}	1950	Average calculated depth to reference mass, cm	35.8
5		3253		60.1
6				
7				
8				
9				
10				

	A	B	C	D	E	F	G	H	I	J	K	L	M
12	Depth	Profile ID	Sample weight	Soil OC conc.	Incr. soil mass	Cum soil mass	Incr. OC mass	Cum OC mass	Cum ref soil mass	Cum ref OC mass	Depth to ref mass	ESM layer	ESM layer OC mass
13	/cm		/g	/g kg^{-1}	/Mg ha^{-1}	/Mg ha^{-1}	/Mg ha^{-1}	/Mg ha^{-1}	/Mg ha^{-1}	/Mg ha^{-1}	/cm	/Mg ha^{-1}	/Mg ha^{-1}
15	30	VM42point1-1	283.2	24.29	1950	1950	47.36	47.36	1950	47.36	30.0	0-1950	47.36
16	50	VM42point1-2	189.2	12.68	1303	3253	16.52	63.89	3253	63.89	50.0	1950-3253	16.52
17													
18													
20	30	VM42point2-1	222.7	28.77	1534	1534	44.1	44.1	1950	49.9	38.3	0-1950	49.9
21	50	VM42point2-2	144.3	10.65	994	2527	10.6	54.7	3253	61.2	64.6	1950-3253	11.3
22													
23													
25	30	VM42point3-1	217.5	20.68	1498	1498	31.0	31.0	1950	36.8	39.1	0-1950	36.8
26	50	VM42point3-2	143.5	11.28	988	2486	11.1	42.1	3253	50.2	65.5	1950-3253	13.4
27													

Note that under Quantification Approach 1, SOC stocks for model initialization may be calculated using Equation (4) where models use SOC stocks as an input rather than ingesting SOC content and bulk density values separately. Where models require bulk density inputs, such bulk density measurements must be taken following the approach described in Section 8.2.1.5.

$$SOC_{model} = 100 \times BD_{corr} \times d \times OC_{n,dl} \tag{4}$$

Where:

SOC_{model} = SOC stock as model input data (t/ha)

BD_{corr} = Corrected bulk density of the fine soil fraction, after subtracting the mass proportion of the coarse fragments (g/cm^3)

d = Soil depth (cm)

100 = Conversion factor from g/cm^2 to t/ha

Finally, modeled SOC stocks under Quantification Approach 1 must be calculated using Equation (5) and following the guidance in *VMD0053*:

$$SOC_{bsl,i,t} = \text{ƒ}(SOC_{bsl,i,t}) \tag{5}$$

Where:

$SOC_{bsl,i,t}$ = Estimated carbon stocks in the SOC pool in the baseline scenario for quantification unit *i* at the end of year *t* (t CO_2e/ha)

$\text{ƒ}(SOC_{bsl,i,t})$ = Modeled SOC stocks in the baseline scenario for quantification unit *i* in year *t*, calculated by modeling SOC stock changes over the course of the preceding year (t CO_2e/ha)

i = Quantification unit

8.2.2 Change in Carbon Stocks in Aboveground and Belowground Woody Biomass

Where carbon stocks in aboveground and belowground woody biomass are included in the project boundary per Table 3~~Table 3~~, the change in carbon stocks in trees ($\Delta C_{TREE,bsl,i,t}$) and shrubs ($\Delta C_{SHRUB,bsl,i,t}$) in the baseline for quantification unit *i* in year *t* 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.*

Where woody biomass is included in the project boundary, the relevant Afforestation, Reforestation, and Revegetation (ARR) requirements in the most recent version of the *VCS Methodology Requirements* apply.[39] Where woody biomass is harvested, projects must calculate the long-term average GHG benefit following guidance in the most recent versions of the *VCS Methodology Requirements* Section 3.6 and the *VCS Standard* Section 3.2.

8.2.3 Carbon Dioxide Emissions from Fossil Fuel Combustion

Where carbon dioxide emissions from fossil fuel are included in the project boundary per Table 3~~Table 3~~, they are quantified in the baseline scenario under Quantification Approach 3, using Equations (6) and (7).

Parameter $\overline{CO_{2}\_ff_{bsl,i,t}}$ is estimated using the following equation:

$$\overline{CO_{2}\_ff_{bsl,i,t}} = \left(\sum_{j=1}^{J} EFF_{bsl,j,i,t}\right)/A_i \tag{6}$$

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[39] VCS Methodology VM0047 Afforestation, Reforestation and Revegetation is the recommended methodology for projects cultivating woody biomass as a primary project activity. The woody biomass quantification approach will be updated in a future revision of VM0042 drawing from approaches used in VM0047.

Where:

$\overline{CO_2\_ff_{bsl,\imath,t}}$ = Areal mean carbon dioxide emissions from fossil fuel combustion in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$EFF_{bsl,j,i,t}$ = Carbon dioxide emissions from fossil fuel combustion in the baseline scenario in vehicle/equipment type *j* for quantification unit *i* in year *t* (t CO_2e)

A_i = Area of quantification unit *i* (ha)

j = Type of fossil fuel (gasoline, diesel or other)

The parameter $EFF_{bsl,j,i,t}$ is estimated using the following equation:

$$EFF_{bsl,j,i,t} = FFC_{bsl,j,i,t} \times EF_{CO2,j} \tag{7}$$

Where:

$FFC_{bsl,j,i,t}$ = Consumption of fossil fuel type *j* for quantification unit *i* in year *t* (liters)

$EF_{CO2,j}$ = Emission factor for combustion of fossil fuel type *j* (t CO_2e/liter)

8.2.4 Carbon Dioxide Emissions from Liming

Application of calcitic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) releases bicarbonate ($2HCO_3^-$), which evolves into CO_2 and water (H_2O) as carbonate limes dissolve. Where one of the ALM practices is liming and resulting carbon dioxide emissions are not deemed de minimis, they are quantified in the baseline scenario under Quantification Approach 3 using Equations (8) and (9).

Parameter $\overline{CO2\_\imath me_{bsl,\imath,t}}$ is estimated using the following equation:

$$\overline{CO2\_\imath me_{bsl,\imath,t}} = EL_{bsl,i,t} \,/A_i \tag{8}$$

Where:

$\overline{CO2\_\imath me_{bsl,\imath,t}}$ = Areal mean carbon dioxide emissions from liming in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$EL_{bsl,i,t}$ = Carbon dioxide emissions from liming in the baseline scenario for quantification unit *i* in year *t* (t CO_2e)

$$EL_{bsl,i,t} = ((M_{Limestone,bsl,i} \times EF_{Limestone}) + (M_{Dolomite,,bsl,i} \times EF_{Dolomite})) \times \frac{44}{12} \tag{9}$$

Where:

$M_{Limestone,bsl,i}$ = Amount of calcitic limestone ($CaCO_3$) applied to quantification unit *i* in year *t* (tonnes)

$EF_{Limestone}$ = Emission factor for calcitic limestone (0.12) (t C/t of limestone)

$M_{Dolomite,bsl,i}$ = Amount of dolomite ($CaMg(CO_3)_2$) applied to quantification unit *i* in year *t* (tonnes)

$EF_{Dolomite}$ = Emission factor for dolomite (0.13) (t C/t of dolomite)

44/12 = Molar mass ratio of CO_2 to C applied to convert CO_2-C emissions to CO_2 emissions

8.2.5 Methane Emissions from the SOC Pool

Where methane emissions from soil methanogenesis are included in the project boundary per Table 3~~Table 3~~, they are quantified in the baseline scenario under Quantification Approach 1 using Equation (10)~~(10)~~.

$$\overline{CH4\_soil_{bsl,i,t}} = GWP_{CH4} \times \int(CH4\_soil_{bsl,i,t}) \tag{10}$$

Where:

$\overline{CH4\_soil_{bsl,i,t}}$ = Areal mean methane emissions from SOC pool in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$\int(CH4\_soil_{bsl,i,t})$ = Modeled methane emissions from soil in the baseline scenario for quantification unit *i* in year *t*, calculated by modeling soil methane fluxes over the course of the preceding year (t CO_2e/ha)

GWP_{CH4} = Global warming potential for CH_4 (t CO_2e/t CH_4)

8.2.6 Methane Emissions from Livestock Enteric Fermentation

Where methane emissions from livestock enteric fermentation are included per Table 3~~Table 3~~, they are quantified in the baseline scenario under Quantification Approach 3 using Equation (11)~~(11)~~. Following the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, quantification must be differentiated by livestock type, manure management system, and productivity system.

$$\overline{CH4\_ent_{bsl,i,t}} = \left(\frac{GWP_{CH4} \times \sum_{l=1}^{L} Pop_{bsl,l,i,t,P} \times EF_{ent,l,P}}{1000}\right)/A_i \tag{11}$$

Where:

$\overline{CH4\_ent_{bsl,i,t}}$ = Areal mean methane emissions from livestock enteric fermentation in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$Pop_{bsl,l,i,t,P}$ = Population of grazing livestock of type *l* in quantification unit *i* for productivity system *P* in year *t* in the baseline scenario (head numbers)

$EF_{ent,l,P}$ = Enteric fermentation emission factor for livestock type *l* in productivity system *P* (kg CH_4/(head × year))

l = Type of livestock

P = Productivity system

1000 = Conversion factor from kg to t

8.2.7 Methane Emissions from Manure Deposition

Where methane emissions from manure deposition are included in the project boundary per Table 3~~Table 3~~, they are quantified in the baseline scenario under Quantification Approach 3 using Equations (12)~~(12)~~ and (13)~~(13)~~.

$$\overline{CH4\_md_{bsl,i,t}} = \frac{GWP_{CH4} \times \sum_{l=1}^{L}(Pop_{bsl,l,i,t,P} \times VS_{l,i,t,P} \times AWMS_{l,i,t,P,S} \times EF_{CH4,md,l,P,S})}{10^6 \times A_i} \qquad (12)$$

Where:

$\overline{CH4\_md_{bsl,i,t}}$ = Baseline areal mean CH_4 emissions from manure deposition in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$VS_{l,i,t,P}$ = Average volatile solids excretion per head for livestock type *l* in quantification unit *i* for productivity system *P* in year *t* (kg volatile solids/~~(~~head~~ × day)~~

$AWMS_{l,i,t,P,S}$ = Fraction of total annual volatile solids for each livestock type *l* in quantification unit *i*, that is managed in manure management system *S* in the project area, for productivity system *P* (dimensionless)

$EF_{CH4,md,l,P,S}$ = Emission factor for methane emissions from manure deposition for livestock type *l* for productivity system *P* in manure management system *S* (g CH_4/kg volatile solids)

S = Manure management system

10^6 = Conversion factor from grams to tonnes

$$VS_{l,i,t,P} = \left(VS_{rate,l,P} \times \frac{W_{bsl,l,i,t,P}}{1000}\right) \times 365 \qquad (13)$$

Where:

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

$W_{bsl,l,i,t,P}$ = Average weight in the baseline scenario of livestock type *l* for quantification unit *i* in productivity system *P* in year *t* (kg animal mass/head)

1000 = Conversion factor kg per tonne

365 = Days per year

8.2.8 Methane Emissions from Biomass Burning

Where methane emissions from biomass burning are included in the project boundary per Table 3~~Table 3~~, they are quantified in the baseline scenario under Quantification Approach 3 using Equation (14)~~(14)~~.

$$\overline{CH4\_bb_{sl,i,t}} = (\frac{GWP_{CH4} \times \sum_{c=1}^{C} MB_{bsl,c,i,t} \times CF_c \times EF_{c,CH4}}{10^6})/A_i \tag{14}$$

Where:

$\overline{CH4\_bb_{bsl,i,t}}$ = Methane emissions in the baseline scenario from biomass burning for quantification unit *i* in year *t* (t CO_2e/ha)

$MB_{bsl,c,i,t}$ = Mass of agricultural residues of type *c* burned in the baseline scenario for quantification unit *i* in year *t* (kg)

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 CH_4/kg dry matter burned)

c = Type of agricultural residue

10^6 = Conversion factor from grams to tonnes

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

Nitrous oxide emissions due to nitrification/denitrification include direct and indirect emissions from nitrogen fertilizers and direct emissions from nitrogen-fixing species. Where nitrous oxide emissions due to nitrogen inputs to soils from nitrogen fertilizers and nitrogen-fixing species are included in the project boundary per Table 3~~Table 3~~, they are quantified in the baseline scenario under Quantification Approaches 1 or 3. Under Quantification Approach 1, Equation (15) is used. Under Quantification Approach 3, Equations (16)–(25)~~(25)~~ are used. Following the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, quantification must be differentiated by livestock type, manure management system, and productivity system.

Quantification Approach 1

Direct and indirect nitrous oxide emissions due to nitrogen inputs to soils (nitrogen fertilizers, manure deposition, and nitrogen-fixing species) in the baseline scenario are quantified as:

$$\overline{N2O\_soil_{bsl,i,t}} = GWP_{N2O} \times f(N2O\_soil_{bsl,i,t}) \tag{15}$$

Where:

$\overline{N2O\_soil_{bsl,i,t}}$ = Areal mean direct and indirect nitrous oxide emissions due to nitrogen inputs to soils in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$f(N2O\_soil_{bsl,i,t})$ = Modeled nitrous oxide emissions from soil in the baseline scenario for quantification unit *i* in year *t*, calculated by modeling soil fluxes of nitrogen forms over the course of the preceding year (t N_2O/ha)

GWP_{N2O} = Global warming potential for N_2O (t CO_2e/t N_2O)

Quantification Approach 3

Nitrous oxide emissions due to nitrogen inputs to soils in the baseline scenario are estimated by applying Equation (16)~~(16)~~.

$$N2O\_soil_{bsl,i,t} = N2O\_fert_{bsl,i.t} + N2O\_md_{bsl,i,t} + N2O\_Nfix_{bsl,i,t} \tag{16}$$

Where:

$N2O\_soil_{bsl,i,t}$ = Nitrous oxide emissions due to nitrogen inputs to soils in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$N2O\_fert_{bsl,i,t}$ = Nitrous oxide emissions due to fertilizer use in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$N2O\_md_{bsl,i,t}$ = Nitrous oxide emissions due to manure deposition in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$N2O\_Nfix_{bsl,i,t}$ = Nitrous oxide emissions from crop residues due to the use of N-fixing species in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

Where nitrous oxide emissions due to fertilizer use are included in the project boundary per Table 3~~Table 3~~, they are quantified in the baseline scenario using Equations (17)~~(17)~~–(23).

$$N2O\_fert_{bsl,i,t} = N2O\_fert_{bsl,direct,i,t} + N2O\_fert_{bsl,indirect,i,t} \tag{17}$$

Where:

$N2O\_fert_{bsl,direct,i,t}$ = Direct nitrous oxide emissions due to fertilizer use in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$N2O\_fert_{bsl,indirect,i,t}$ = Indirect nitrous oxide emissions due to fertilizer use in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

Direct nitrous oxide emissions due to fertilizer use in the baseline scenario are quantified in Equations (18)~~(18)~~–(20)~~(20)~~.

$$\overline{N2O\_fert_{bsl,direct,i,t}} = ((FSN_{bsl,i,t} + FON_{bsl,i,t}) \times EF_{Ndirect} \times 44/28 \times GWP_{N2O})/A_i \tag{18}$$

$$FSN_{bsl,i,t} = \sum_{SF} M_{bsl,SF,i,t} \times NC_{SF} \tag{19}$$

$$FON_{bsl,i,t} = \sum_{OF} M_{bsl,OF,i,t} \times NC_{OF} \tag{20}$$

Where:

$\overline{N2O\_fert_{bsl,direct,i,t}}$ = Areal mean direct nitrous oxide emissions due to fertilizer use in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$FSN_{bsl,i,t}$ = Synthetic N fertilizer applied to quantification unit *i* in year *t* in the baseline scenario (t N)

$FON_{bsl,i,t}$ = Organic N fertilizer applied to quantification unit *i* in year *t* in the baseline scenario (t N)

$EF_{Ndirect}$ = Emission factor for nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments, and crop residues (t N_2O-N/t N applied)

$M_{bsl,SF,i,t}$ = Mass of N-containing synthetic fertilizer type *SF* applied to quantification unit *i* in year *t* in the baseline scenario (t fertilizer)

NC_{SF} = N content of synthetic fertilizer type *SF* (t N/t fertilizer)

$M_{bsl,OF,i,t}$ = Mass of N-containing organic fertilizer type *OF* applied to quantification unit *i* in year *t* in the baseline scenario (t fertilizer)

NC_{OF} = N content of organic fertilizer type *OF* (t N/t fertilizer)

SF = Synthetic N fertilizer type

OF = Organic N fertilizer type

44/28 = Molar mass ratio of N_2O to N applied to convert N_2O-N emissions to N_2O emissions

Indirect nitrous oxide emissions due to fertilizer use in the baseline scenario are quantified in Equations (21)~~(21)~~–(23)~~(23)~~.

$$\overline{N2O\_fert_{bsl,indirect,i,t}} = (N2O\_fert_{bsl,volat,i,t} + N2O\_fert_{bsl,leach,i,t})/A_i \tag{21}$$

$$N2O\_fert_{bsl,volat,i,t} = \begin{bmatrix} (FSN_{bsl,i,t} \times Frac_{GASF,l,S}) + \\ (FON_{bsl,i,t} \times Frac_{GASM,l,S}) \end{bmatrix} \times EF_{Nvolat} \times 44/28 \times GWP_{N2O} \tag{22}$$

$$N2O\_fert_{bsl,leach,i,t} = \begin{pmatrix} FSN_{bsl,i,t} + \\ FON_{bsl,i,t} \end{pmatrix} \times Frac_{LEACH,l,S} \times EF_{Nleach} \times \frac{44}{28} \times GWP_{N2O} \tag{23}$$

Where:

$\overline{N2O\_fert_{bsl,indirect,i,t}}$ = Areal mean indirect nitrous oxide emissions due to fertilizer use in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$N2O\_fert_{bsl,volat,i,t}$ = Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to fertilizer use in the baseline scenario in quantification unit *i* in year *t* (t CO_2e)

$N2O\_fert_{bsl,leach,i,t}$ = Indirect nitrous oxide emissions produced from leaching and runoff of N, in regions where leaching and runoff occurs, due to fertilizer use in the baseline scenario in quantification unit *i* in year *t* (t CO_2e)

$Frac_{GASF}$ = Fraction of all synthetic N added to soils that volatilizes as NH_3 and NO_x (dimensionless)

$Frac_{GASM}$ = 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 (dimensionless)

EF_{Nvolat} = Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces (t N_2O-N/(t NH_3-N + NO_x-N volatilized))

$Frac_{LEACH}$ = Fraction of N (synthetic or organic) added 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)

EF_{Nleach} = Emission factor for nitrous oxide emissions from leaching and runoff (t N_2O-N/t N leached and runoff)

Where nitrous oxide emissions due to the use of N-fixing species are included in the project boundary per Table 3~~Table 3~~, they are quantified in the baseline scenario using Equations (24)~~(24)~~ and (25)~~(25)~~.

$$\overline{N2O\_Nfix_{bsl,i,t}} = (F_{CR,bsl,i,t} \times EF_{Ndirect} \times \frac{44}{28} \times GWP_{N2O})/A_i \tag{24}$$

Where:

$\overline{N2O\_Nfix_{bsl,i,t}}$ = Areal mean nitrous oxide emissions from crop residues due to the use of N-fixing species in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$F_{CR,bsl,i,t}$ = Amount of N in N-fixing species (above- and belowground) returned to soils in the baseline scenario for quantification unit *i* in year *t* (t N)

$$F_{CR,bsl,i,t} = \sum_{g=1}^{G} MB_{g,bsl,i,t} \times N_{content,g} \tag{25}$$

Where:

$MB_{g,bsl,i,t}$ = Annual dry matter (above- and belowground) of N-fixing species *g* returned to soils for quantification unit *i* in year *t* (t d.m.)

$N_{content,g}$ = Fraction of N in dry matter for N-fixing species *g* (t N/t d.m.)

g = Type of N-fixing species

8.2.10 Nitrous Oxide Emissions from Manure Deposition

Where nitrous oxide emissions due to manure deposition are included in the project boundary per Table 3~~Table 3~~, they are quantified in the baseline scenario under Quantification Approach 3 using Equations (26)~~(26)~~–(31)~~(31)~~.

$$\overline{N2O\_md_{bsl,i,t}} = N2O\_md_{bsl,direct,i,t} + N2O\_md_{bsl,indirect,i,t} \tag{26}$$

Where:

$\overline{N2O\_md_{bsl,i,t}}$ = Areal mean nitrous oxide emissions due to manure deposition in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$N2O\_md_{bsl,direct,i,t}$ = Direct nitrous oxide emissions due to manure deposition in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$N2O\_md_{bsl,indirect,i,t}$ = Indirect nitrous oxide emissions due to manure deposition in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

Direct nitrous oxide emissions due to manure deposition in the baseline scenario are quantified using Equations (27)~~(27)~~ and (28)~~(28)~~.

$$\overline{N2O\_md_{bsl,direct,i,t,P,S}} = \frac{\sum_{l=1}^{L} F_{bsl,manure,l,i,t,P} \times EF_{N2O,md,l,S} \times 44/28 \times GWP_{N2O}}{1000 \times A_i} \tag{27}$$

$$F_{bsl,manure,l,i,t,P} = \left(Pop_{bsl,l,i,t} \times Nex_{l,P}\right) \times AWMS_{l,i,t,P,S} \times MS_{bsl,l,i,t} \tag{28}$$

Where:

$\overline{N2O\_md_{bsl,direct,i,t,P,S}}$ = Areal mean direct nitrous oxide emissions due to manure deposition in the baseline scenario for quantification unit *i* for productivity system *P* and manure management system *S* in year *t* (t CO_2e/ha)

$F_{bsl,manure,l,i,t,P}$ = Amount of nitrogen in manure and urine deposited on soils by livestock type *l* for productivity system *P* in quantification unit *i* in year *t* (t N)

$Nex_{l,P}$ = Average annual nitrogen excretion per head of livestock type *l* for productivity system *P* (kg N deposited/(head × year))

$EF_{N2O,md,l,S}$ = Emission factor for nitrous oxide from manure and urine deposited on soils by livestock type *l* for manure management system *S* (kg N_2O-N/kg N input)

$MS_{bsl,l,i,t}$ = Baseline fraction of total annual N excretion for each livestock type *l* for quantification unit *i* in year *t* that is deposited on the project area (%)

1000 = Conversion factor from kg to t

Indirect nitrous oxide emissions due to manure deposition in the baseline scenario are quantified under Quantification Approach 3 using Equations (29)~~(29)~~-(31)~~(31)~~.

$$\overline{N2O\_md_{bsl,indirect,i,t}} = (N2O\_md_{bsl,volat,i,t} + N2O\_md_{bsl,leach,i,t})/A_i \tag{29}$$

$$N2O\_md_{bsl,volat,i,t} = F_{bsl,manure,l,i,t,P} \times Frac_{GASM,l,S} \times EF_{Nvolat} \times \frac{44}{28} \times GWP_{N2O} \tag{30}$$

$$N2O\_md_{bsl,leach,i,t} = F_{bsl,manure,l,i,t,P} \times Frac_{LEACH,l,S} \times EF_{Nleach} \times \frac{44}{28} \times GWP_{N2O} \tag{31}$$

Where:

$\overline{N2O\_md_{bsl,indirect,i,t}}$ = Areal mean indirect nitrous oxide emissions due to manure deposition in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$N2O\_md_{bsl,volat,i,t}$ = Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to manure deposition for quantification unit *i* in year *t* (t CO_2e)

$N2O\_md_{bsl,leach,i,t}$ = 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 quantification unit *i* in year *t*. Equal to zero where annual precipitation is less than potential evapotranspiration, unless irrigation is employed (t CO_2e)

8.2.11 Nitrous Oxide Emissions from Biomass Burning

Nitrous oxide emissions from biomass burning in the baseline scenario are quantified under Quantification Approach 3.

Parameter $\overline{N2O\_bb_{bsl,i,t}}$ is estimated using Equation (32)~~(32)~~.

$$\overline{N2O\_bb_{bsl,i,t}} = \left(\frac{GWP_{N2O} \times \sum_{c=1}^{C} MB_{bsl,c,i,t} \times CF_c \times EF_{c,N2O}}{10^6}\right)/A_i \tag{32}$$

Where:

$\overline{N2O\_bb_{bsl,i,t}}$ = Areal mean nitrous oxide emissions in the baseline scenario from biomass burning for quantification unit *i* in year *t* (t CO_2e/ha)

$EF_{c,N2O}$ = Nitrous oxide emission factor for the burning of agricultural residue type *c* (g N_2O/kg dry matter burnt)

10^6 = Conversion factor from grams to tonnes

8.3 Project Emissions

Stock change/emissions resulting from project scenario ALM activities are calculated or modeled based on monitored inputs. Project scenario CO_2, CH_4, and N_2O emissions must be quantified following the approaches found in Table 5~~Table 5~~ and using the equations provided in Section 8.2. For all equations, the subscript *bsl* must be substituted by *wp* to make it clear that the relevant values are being quantified for the project scenario. Further, as per Section 8.4.2, where livestock are included in the baseline, the project must use at a minimum the average livestock value from the historical look-back period.

Quantification Approach 1

Model inputs must be collected following the guidance in Table 8~~Table 8~~.

Table 8: Guidance on collection of model inputs, where required by the model selected, for Quantification Approach 1 for the project scenario

Model Input Category	Timing	Approach
SOC content to calculate SOC stocks	Determined at project start via direct measurements at *t* = 0 or (back-) modeled to *t* = 0 from measurements collected within ±5 years of *t* = 0. Subsequent measurements are required every five years or more frequently.	Directly measured via conventional analytical laboratory methods — for example dry combustion or proximal sensing techniques (INS, LIBS, MIR, and Vis-NIR) — with known uncertainty, following the criteria in Appendix 4 and *VMD0053* guidance. See parameter table for $\overline{SOC_{wp,i,t}}$.
Bulk density to calculate SOC stocks (initial)	Determined prior to project intervention via direct measurements at t = 0 or from measurements collected within ±5 years of t = 0	See Section 8.2.1.5
Soil properties (other than bulk density and SOC)	Determined ex ante	Measured or determined from published soil maps with known uncertainty. Estimates from direct measurements must: 1) Be derived from representative (unbiased) sampling; and 2) Ensure accuracy of measurements through adherence to best practices (to be determined by the project proponent and outlined in the monitoring plan).

Climate variables (e.g., precipitation, temperature)	Continuously monitored ex post	Measured for each model-specific meteorological input variable at its required temporal frequency (e.g., daily) for the model prediction interval. Measurements are taken at the closest continuously monitored weather station not exceeding 50 km from the sample field, or from a synthetic weather station (e.g., PRISM[40]).
ALM activities (as identified following procedures in *VMD0053*, referencing categories of practices outlined in Applicability Condition 1)	Monitored ex post	Required model inputs related to ALM practices must be monitored and recorded for each project year *t*. Information on ALM practices is monitored via consultation with, and substantiated with a signed attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected sample field and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications). Units for quantitative information will be based on model input requirements.

Quantification Approach 2

Quantification Approach 2 is used to estimate emissions from SOC stocks only. Remeasurements in both baseline control sites and the project area must be conducted at least every five years, or prior to each verification event where verification occurs more frequently. SOC stocks in the project scenario ($SOC_{wp,i,t}$) are calculated on an equivalent soil mass (ESM) basis by multiplication with the SOC content in each quantification unit or stratum at time $t - 1$, directly measured in each sample field. Where bulk density is measured in a fixed depth approach, mass corrections may be applied to meet the ESM requirement.

A detailed description of SOC stock calculations with multiple soil depth increments, and spreadsheets and R scripts to standardize and facilitate calculations on an ESM basis, are provided in Wendt and Hauser (2013) and von Haden et al. (2020). SOC stock changes are calculated in Equations (3) to (5).

Quantification Approach 3

Project emissions are calculated for each sample field using applicable default values and any monitored parameters. The most accurate available emission factor applicable to the project conditions must be used, in the following descending order of preference:

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[40] Available at: https://climatedataguide.ucar.edu/climate-data/prism-high-resolution-spatial-climate-data-united-states-maxmin-temp-dewpoint

1) Where available, a project-specific emission factor from a peer-reviewed scientific publication[41] must be used.

2) Where there is no relevant peer-reviewed scientific literature, the project proponent may propose alternative sources of information (e.g., government databases, industry publications) to establish the default factor(s) and must provide evidence that the alternative source of information is robust and credible (e.g., independent expert attestation).

3) Where no alternative information source is available that is applicable to the project conditions, project proponents may derive emission factors using activity data collected during the project by following the guidance to derive Tier 2 emission factors in the respective sections of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

4) Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a emission factors from the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* may be selected.

Woody Biomass

Aboveground woody biomass must be included where project activities may significantly reduce this 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*. Where woody biomass is harvested, projects must calculate the long-term average GHG benefit following the guidance in the most recent versions of the *VCS Methodology Requirements* Section 3.6 and the *VCS Standard* Section 3.2.

8.4 Leakage

Improved ALM projects may result in leakage through: new application of organic amendments from outside the project area (i.e., organic amendments applied in the project from outside of the project area, that were not previously applied in the historical look-back period); productivity declines; displacement of livestock outside of the project boundary; and/or diversion of biomass residues that were used for bioenergy applications in the baseline scenario. Guidance on how to account for each type of leakage is provided below.

As mentioned in Section 5, where the sum of increases in GHG emissions from any leakage source is less than 5% of the total net anthropogenic reductions and removals due to the

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[41] As stated in Section 2.5 of the most recent version of the *VCS Methodology Requirements*, peer-reviewed scientific literature used to derive (default) emission factors must be published in a journal indexed in the Web of Science: Science Citation Index.

project, such sources may be deemed de minimis and may be ignored. This must be demonstrated via application of the CDM *Tool for testing significance of GHG emissions in A/R CDM project activities*.

8.4.1 Accounting for Leakage from New Application of Organic Amendments from Outside the Project Area

Where new[42] or additional[43] manure, compost, or biosolids[44] are applied in the project that were not applied in the historical look-back period, there is a risk of activity-shifting leakage if the organic amendments were applied to other fields before the project and their application is diverted to the fields participating in the project. To account for this type of leakage, a deduction must be used unless any of the following apply:

1) The manure or compost applied as a project activity in the project are newly produced on-site from farms within the project area;
2) The manure is documented to have been diverted from an uncontrolled anaerobic lagoon, pond, tank, or pit[45] from which there is no recovery of methane for generation of heat and/or electricity; or
3) The manure, compost, or biosolids are documented to not have been used as a soil amendment.

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

Equation (33)~~(33)~~ estimates the leakage from imported manure, compost, or biosolids that are diverted from other applications and could have led to an increase in SOC outside the project boundary in the absence of the project activity. The total amount of carbon applied is reduced to 12% based on the global manure C retention coefficient from Maillard and Angers (2014). This value reflects the fraction of manure carbon expected to remain in project area soils. While derived for manure, the equation is also conservatively applied to compost or biosolids in this methodology.

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[42] In this context, “new” refers to organic amendment application to fields that did not have organic amendment applied during the historical look-back period.

[43] In this context, “additional” refers to organic amendment application to fields that had organic amendment applied during the historical look-back period, where the amount of organic amendment increases in the project scenario.

[44] Biosolids are the nutrient-rich organic materials resulting from the treatment of domestic sewage in a wastewater treatment facility (i.e., treated sewage sludge).

[45] Where manure is diverted for field application, rather than stored anaerobically in an uncontrolled lagoon, pond, tank, or pit, the avoided methane emissions will far outweigh the SOC impacts. Where 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 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

$$LE_{OA,t} = \sum_{l} \left(M\_OA_{wp,l,t} \times CC_{wp,oa,t} \times 0.12 \times \frac{44}{12} \right) \tag{33}$$

Where:

$LE_{OA,t}$ = Leakage from organic amendments in year t (t CO_2e)

$M\_OA_{wp,l,t}$ = Mass of organic amendment applied as fertilizer in the project area in year t, disaggregated by livestock type l for manure (tonnes)

$CC_{wp,oa,t}$ = Carbon content of organic amendment applied as fertilizer in the project area in year t, disaggregated by livestock type l for manure (t C/t organic amendment)

0.12 = Fraction of manure (i.e., organic amendment) carbon expected to remain in project area soils (unitless)

44/12 = Ratio of molecular weight of carbon dioxide to carbon

8.4.2 Accounting for Leakage from Livestock Displacement

CH_4 and N_2O emissions from livestock production are dependent on livestock population (see Sections 8.2.6, 8.2.7, and 8.2.10). To avoid crediting reductions resulting from livestock displacement (i.e., lowering of CH_4 and N_2O emissions within the project area relative to the baseline by reducing the number of livestock within the project boundary), when a livestock population decline occurs in the project scenario, project proponents must either:

a) use the livestock population in the baseline scenario to calculate with-project emissions and quantify leakage from livestock displacement using *VMD0054 Module for Estimating Leakage from ARR Activities* as per equation (36)~~(36)~~, OR;

b) demonstrate that the project scenario commodity production (e.g., meat, dairy, fiber) did not decrease and that livestock was not displaced but slaughtered. In this case, the project proponent must quantify emissions with project scenario livestock populations and assume that no leakage from livestock displacement occurs (i.e., in equation (36)~~(36)~~, $LK_{disp,t} = 0$).

Where livestock production declines in the project scenario relative to the baseline scenario, projects must account for this foregone production as described in Section 8.4.3.

8.4.3 Accounting for Leakage from Production Declines

Project proponents must account for leakage from production declines in the initial years of a project[46] or due to changes in overall crop or livestock products produced. To do so, project proponents must apply the most recent version of *VMD0054* as modified by the following:

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[46] Initial implementation of improved ALM practices may lead to some declines in productivity as the producer adjusts their operation.

1) Throughout *VMD0054*, read “ALM” and “Agricultural Land Management” in place of “ARR” and “Afforestation, Reforestation, and Revegetation”; and read “*VM0042 Improved Agricultural Management*” in place of “*VM0047 Afforestation, Reforestation, and Revegetation*.”

2) Replace Equation (5) in *VMD0054, v1.0*[47] with the following equation to incorporate the land sparing effect of adding new agricultural commodities. Read “production change” in place of “foregone production” when defining parameter l and throughout *VMD0054*, revising its definition to remove “minimum value is zero.”

$$l_{j,t} = FP_{j,t} - LM_{j,t} \tag{34}$$

3) Replace Equation (7) in *VMD0054, v1.0* with the following equation to limit the area generating leakage to only that which results in net land conversion (where *AL* is greater than zero). This prevents calculating positive leakage in the event of net land sparing from changes in agricultural commodity production.

$$AL_t = MAX\left(\sum_{j=1}^{T} INL_{j,t}\ ,0\right) \tag{35}$$

4) Use the outcome of Equation (10) from *VMD0054, v1.0* to quantify annual leakage from displaced production as follows:

$$LK_{disp,t} = \frac{MAX(0, LK_t - LK_{prior})}{years} \tag{36}$$

Where:

$LK_{disp,t}$ = Leakage emissions from ~~livestock displacement~~displaced production in year *t* (t CO_2e)

LK_t = Cumulative leakage up to year *t* calculated using *VMD0054* (t CO_2e)

LK_{prior} = Cumulative leakage between $y = 0$ and the previous verification event, calculated using *VMD0054* (t CO_2e)

years = Duration of the verification period (years)

8.4.4 Accounting for Leakage from Diversion of Biomass Residues Used for Energy Applications in the Baseline Scenario

Where manure or crop residue management is a component of the project activity, and the manure or crop residues are diverted from energy applications (e.g., fuel for cookstoves or biomass power generation) in the baseline scenario there is a risk of leakage. Implementation of the project activity may force these competing energy applications to use inputs which are not carbon neutral. Leakage emissions $LE_{BR,Div,t}$ must be determined following procedures in

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[47] Or equivalent equation in a newer version of *VMD0054*

the CDM's *TOOL16: Project and leakage emissions from biomass,*[48] Section 6,2 Leakage due to diversion of biomass residues from other applications in year *y*.[49]

8.5 Net Reductions and Removals

GHG emission reductions occur when:

1) Carbon stocks decrease from year *t* to year *t* + 1 in the baseline scenario and, to a lesser extent, in the project scenario.[50] The cumulative carbon stock change in the project scenario is negative or zero (i.e., the project carbon stock at the end of the verification period is less than or equal to the carbon stock at the project start date).
2) Carbon stocks decrease from year *t* to year *t* + 1 in the baseline scenario and, carbon stocks increase in the project scenario. Note that this variation may also generate carbon removals as described in paragraph (2) in introduction of equation 40, below.
3) CO_2 emissions from fossil fuel combustion and liming are lower in the project than in the baseline scenario.
4) CH_4 emissions from the SOC pool (i.e., through soil methanogenesis), livestock enteric fermentation, manure deposition, and biomass burning are lower in the project than in the baseline scenario.
5) N_2O emissions from nitrogen fertilizers and nitrogen-fixing species, manure deposition, and biomass burning are lower in the project than in the baseline scenario.

GHG emission reductions before allocation of leakage emissions are quantified as:

$$\begin{aligned} ER_t = \; & I(\Delta CO2_{wp}) \\ & \times \Big(\Delta CO2\_ff_t + \Delta CO2\_lime_t + \Delta CH4\_ent_t + \Delta CH4\_md_t \\ & + \Delta CH4\_bb_t + \big(\Delta CH4\_soil_t \times (1 - UNC_{t,CH4\_soil})\big) \\ & + \big(\Delta N2O\_soil_t \times (1 - UNC_{t,N2O\_soil})\big) + \Delta N2O\_bb_t \\ & + \mathrm{MIN}(0, \Delta CO2_{wp,t}) - \mathrm{MIN}(0, \Delta CO2_{bsl,t})\Big) \\ & + \big(1 - I(\Delta CO2_{wp})\big) \times \end{aligned} \tag{37}$$

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[48] See Section "Leakage due to diversion of biomass residues from other applications" in the latest version of CDM TOOL16.

[49] For consistency with other parameters in Equation (38), the subscript t pertaining to "year" is used instead of y as in the CDM tool.

[50] In this case, the project activity would decelerate the decrease in carbon stocks over time, avoiding emissions in the considered timeframe.

$$
\begin{aligned}
(\Delta CO2\_ff_t + \Delta CO2\_lime_t + \ \Delta CH4\_ent_t + \Delta CH4\_md_t + \Delta CH4\_bb_t \\
+ \left(\Delta CH4\_soil_t \ \times \ (1 - \ UNC_{t,CH4\_soil})\right) \\
+ \left(\Delta N2O\_soil_t \ \times \ (1 - \ UNC_{t,N2O\_soil})\right) + \Delta N2O\_bb_t \\
+ \mathrm{MIN}\left(0, \Delta CO2_{wp,t}\right) - \mathrm{MIN}(0, \Delta CO2_{bsl,t}) \\
+ \mathrm{MAX}\left(0, \Delta CO2_{wp,t}\right) - \mathrm{MAX}(0, \Delta CO2_{bsl,t}))
\end{aligned}
$$

Where:

$I\left(\Delta CO2_{wp}\right) = 1$ if $\sum_1^t \Delta CO2_{wp,t} > 0$ and;

$I\left(\Delta CO2_{wp}\right) = 0$ if $\sum_1^t \Delta CO2_{wp,t} \leq 0$

$I(\Delta CO2_{wp})$ = Switches on the first part of Equation (37) when the cumulative carbon stock change in the project scenario is positive, and the second part when the carbon stock change is negative

ER_t = Estimated reductions in year *t* (t CO_2e)

$\Delta CO2\_ff_t$ = Total GHG emission reductions from fossil fuel combustion in year *t* (t CO_2e)

$\Delta CO2\_lime_t$ = Total carbon dioxide emission reductions from liming in year *t* (t CO_2e)

$\Delta CH4\_ent_t$ = Total methane emission reductions from livestock enteric fermentation in year *t* (t CO_2e)

$\Delta CH4\_md_t$ = Total methane emission reductions from manure deposition in year *t* (t CO_2e)

$\Delta CH4\_bb_t$ = Total methane emission reductions from avoided or reduced biomass burning in year *t* (t CO_2e)

$\Delta CH4\_soil_t$ = Total methane emission reductions from increasing uptake into the SOC pool in year *t* (t CO_2e)

$UNC_{t,CH4\_soil}$ = Uncertainty deduction in year *t* when using Quantification Approach 1 to model methane emission reductions from increasing uptake into the SOC pool (fraction between 0 and 1)

$\Delta N2O\_soil_t$ = Total nitrous oxide emission reductions from nitrification/denitrification in year *t* (t CO_2e)

$UNC_{t,N2O\_soil}$ = Uncertainty deduction in year *t* when using Quantification Approach 1 to model nitrous oxide emission reductions from nitrification/denitrification (fraction between 0 and 1)

$\Delta N2O\_bb_t$ = Total nitrous oxide emission reductions from avoided or reduced biomass burning in year *t* (t CO_2e)

$\Delta CO2_{wp,t}$ = Total carbon stock change in the project scenario in year *t* (t CO_2e)

$\Delta CO2_{bsl,t}$ = Total carbon stock change in the baseline scenario in year *t* (t CO_2e)

Net GHG emission reductions are quantified as:

$$ER_{NET,t} = ER_t - LK_{ER,t} \tag{38}$$

Where:

$ER_{NET,t}$ = Estimated net GHG emission reductions in year *t* (t CO_2e)
$LK_{ER,t}$ = Leakage allocated to GHG emission reductions in year *t* (t CO_2e)

Leakage allocated to emission reductions ($LK_{ER,t}$) is calculated as:

$$LK_{ER,t} = (LE_{OA,t} + LK_{disp,t} + LE_{BR,t}) \times \frac{ER_t}{ER_t + CR_t} \tag{39}$$

Where:

$LE_{BR,t}$ = Leakage emissions from the diversion of manure or crop residues from baseline energy applications in year *t* (t CO_2e)
$LK_{disp,t}$ = Leakage emissions from displaced production in year *t* (t CO_2e)
CR_t = Estimated carbon dioxide removals in year *t* (t CO_2e)

Carbon dioxide removals occur when the cumulative carbon stock change in the project scenario is positive (i.e., the project carbon stock is higher than at the project start date). Then, possible annual stock variation includes:

1) Carbon stocks increase from year *t* to year *t* + 1 in the baseline scenario and, to a greater extent, in the project scenario.[51]
2) Carbon stocks decrease from year *t* to year *t* + 1 in the baseline scenario and carbon stocks increase from year *t* to year *t* + 1 in the project scenario.[52]

Carbon dioxide removals are quantified as:

$$CR_t = I(\Delta CO2_{wp}) \times (\mathrm{MAX}(0, \Delta CO2_{wp,t}) - \mathrm{MAX}(0, \Delta CO2_{bsl,t})) \tag{40}$$

Where:

$I(\Delta CO2_{wp}) = 1$ if $\sum_1^t \Delta CO2_{wp,t} > 0$ and;

$I(\Delta CO2_{wp}) = 0$ if $\sum_1^t \Delta CO2_{wp,t} \leq 0$

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[51] In this case, CO_2 removals would occur in the baseline scenario and the project activity enhances removals in the considered timeframe.

[52] In this case, the project activity leads to avoiding emissions that would occur in the baseline scenario in the considered timeframe, and increases carbon stocks beyond the level at the project start date, resulting in CO_2 removals.

$I(\Delta CO2_{wp})$ = Switches Equation (40) on when the cumulative carbon stock change in the project scenario is positive, and off when the change is negative

Net carbon dioxide removals are quantified as:

$$CR_{NET,t} = CR_t - LK_{CR,t} \tag{41}$$

Where:

$CR_{NET,t}$ = Estimated net carbon dioxide removals in year *t* (t CO_2e)
$LK_{CR,t}$ = Leakage allocated to carbon dioxide removals in year *t* (t CO_2e)

Leakage allocated to carbon dioxide removals ($LK_{CR,t}$) is calculated as:

$$LK_{CR,t} = (LE_{OA,t} + LK_{disp,t} + LE_{BR,t}) \times \frac{CR_t}{ER_t + CR_t} \tag{42}$$

Net reductions and removals are quantified as:

$$ERR_{NET,t} = ER_{NET,t} + CR_{NET,t} \tag{43}$$

Where:

$ERR_{NET,t}$ = Estimated net reductions and removals in year *t* (t CO_2e)

In the following subsections, reductions are calculated by subtracting project (subscript *wp*) from baseline (subscript *bsl*) emissions, as the emissions are expected to be lower in the project than in the baseline scenario. On the contrary, removals are calculated by subtracting baseline C stocks from project C stocks, as C stocks are expected to be higher in the project than in the baseline scenario.

8.5.1 Carbon Stock Changes

Total carbon stock change in the baseline scenario in year *t* is quantified as:

$$\Delta CO2_{bsl,t} = \Delta CO2\_soil_{bsl,t} \times \left(1 - UNC_{t,CO2} \times I(\Delta CO2\_soil_t)\right) + \Delta C_{TREE,bsl,t} + \Delta C_{SHRUB,bsl,t} \tag{44}$$

$I(\Delta CO2\_soil\__t) = +1$ if $\Delta CO2\_soil_{wp,t} - \Delta CO2\_soil_{bsl,t} \geq 0$ and;

$I(\Delta CO2\_soil\__t) = -1$ if $\Delta CO2\_soil_{wp,t} - \Delta CO2\_soil_{bsl,t} < 0$

Where:

$\Delta CO2\_soil_{bsl,t}$ = SOC stock change in the baseline scenario in year *t* (t CO_2e)
$UNC_{t,CO2}$ = Uncertainty deduction in year *t* associated with modeling or measuring SOC stock changes (fraction between 0 and 1)
$I(\Delta CO2\_soil_t)$ = Changes the sign of the Uncertainty $UNC_{t,CO2}$ from positive to negative when the SOC stock change between project and baseline scenario is negative (see note below) ensuring a conservative application of uncertainty when SOC losses result in emissions instead of removals.
$\Delta C_{TREE,bsl,t}$ = Carbon stock change in tree biomass in the baseline scenario in year *t* (t CO_2e)
$\Delta C_{SHRUB,bsl,t}$ = Carbon stock change in shrub biomass in the baseline scenario in year *t* (t CO_2e)

Note – When the SOC stocks in the project scenario decrease more rapidly or increase less rapidly than in the baseline scenario, the application of the $I(\Delta CO2\_soil_t)$ function ensures that the uncertainty deduction multiplier is a value >1 adding up the SOC losses. In the more usual case where SOC stock increases in the project scenario are higher than in the baseline scenario, the uncertainty deduction multiplier remains a value between 0 and 1 resulting in a deduction.

Total carbon stock change in the project scenario in year *t* is quantified as:

$$\Delta CO2_{wp,t} = \Delta CO2\_soil_{wp,t} \times \left(1 - UNC_{t,CO2} \times I(\Delta CO2\_soil_t)\right) + \Delta C_{TREE,wp,t} + \Delta C_{SHRUB,wp,t} \tag{45}$$

$I(\Delta CO2_{soilt}) = 1$ if $\Delta CO2\_soil_{wp,t} - \Delta CO2\_soil_{bsl,t} \geq 0$ and;

$I(\Delta CO2_{soilt}) = -1$ if $\Delta CO2\_soil_{wp,t} - \Delta CO2\_soil_{bsl,t} < 0$

Where:

$\Delta CO2\_soil_{wp,t}$ = SOC stock change in the project scenario in year *t* (t CO_2e)
$\Delta C_{TREE,wp,t}$ = Carbon stock change in tree biomass in the project scenario in year *t* (t CO_2e)
$\Delta C_{SHRUB,wp,t}$ = Carbon stock change in shrub biomass in the project scenario in year *t* (t CO_2e)

Quantification unit SOC stock change in the baseline scenario in year *t* is quantified as:

$$\Delta CO2\_soil_{bsl,t} = \sum_{i=1}^{n} \left(\left(\overline{SOC_{bsl,i,t}} - \overline{SOC_{bsl,i,t-x}} \right) \times \frac{1}{x} \right) \times A_i \tag{46}$$

Where:

$\overline{SOC_{bsl,\imath,t}}$ = Areal mean carbon stocks in the SOC pool in the baseline scenario for quantification unit *i* at the end of year *t* (t CO_2e/ha)

$\overline{SOC_{bsl,\imath,t-x}}$ = Areal mean carbon stocks in the SOC pool in the baseline scenario for quantification unit *i* at the end of year *t* − *x* (t CO_2e/ha)

x = Length of the verification period (years)

A_i = Area of quantification unit *i* (ha)

Quantification unit SOC stock change in the project scenario in year *t* is quantified as:

$$\Delta CO2\_soil_{wp,t} = \sum_{i=1}^{n} \left(\left(\overline{SC_{wp,\imath,t}} - \overline{SOC_{wp,\imath,t-x}} \right) \times \frac{1}{x} \right) \times A_i \tag{47}$$

Where:

$\overline{SOC_{wp,\imath,t}}$ = Areal mean carbon stocks in the SOC pool in the project scenario for quantification unit *i* at the end of year *t* (t CO_2e/ha)

$\overline{SOC_{wp,\imath,t-x}}$ = Areal mean carbon stocks in the SOC pool in the project scenario for quantification unit *i* at the end of year *t* − *x* (t CO_2e/ha)

Note - SOC stock changes must be converted to t CO_2e using the factor 44/12 (ratio of molecular weight of carbon dioxide to carbon).

For Quantification Approach 2, SOC stock changes for quantification unit *i* in year *t* are compared to the estimated SOC stock change in baseline control sites. The mean SOC stock per hectare of each “project site–baseline control site” combination should be used. Where measurements are conducted less frequently than every year, results must be divided by the number of years to calculate an annual SOC stock change.

Tree biomass carbon stock change in the baseline scenario in year *t* is quantified as:

$$\Delta C_{TREE,bsl,t} = \sum_{i=1}^{n} \left(\overline{\Delta C_{TREE,bsl,i,t}} - \overline{\Delta C_{TREE,bsl,i,t-x}} \right) \times \frac{1}{x} \times A_i \tag{48}$$

Where:

$\overline{\Delta C_{TREE,bsl,i,t}}$ = Areal mean baseline carbon stock change in tree biomass for quantification unit *i* in year *t* (t CO_2e/ha)

$\overline{\Delta C_{TREE,bsl,i,t-x}}$ = Areal mean baseline carbon stock change in tree biomass for quantification unit *i* in year *t* − *x* (t CO_2e/ha)

Tree biomass carbon stock change in the project scenario in year *t* is quantified as:

$$\Delta C_{TREE,wp,t} = \sum_{i=1}^{n} \left(\overline{\Delta C_{TREE,wp,i,t}} - \overline{\Delta C_{TREE,wp,i,t-x}} \right) \times \frac{1}{x} \times A_i \tag{49}$$

Where:

$\overline{\Delta C_{TREE,wp,i,t}}$ = Areal mean project scenario carbon stock change in tree biomass for quantification unit *i* in year *t* (t CO2e/ha)

$\overline{\Delta C_{TREE,wp,i,t-x}}$ = Areal mean project scenario carbon stock change in tree biomass for quantification unit *i* in year *t* – *x* (t CO2e/ha)

Shrub biomass carbon stock change in the baseline scenario is quantified as:

$$\Delta C_{SHRUB,bsl,t} = \sum_{i=1}^{n} \left(\overline{\Delta C_{SHRUB,bsl,i,t}} - \overline{\Delta C_{SHRUB,bsl,i,t-x}}\right) \times \frac{1}{x} \times A_i \tag{50}$$

Where:

$\overline{\Delta C_{SHRUB,bsl,i,t}}$ = Areal mean baseline carbon stock change in shrub biomass for quantification unit *i* in year *t* (t CO2e/ha)

$\overline{\Delta C_{SHRUB,bsl,i,t-x}}$ = Areal mean baseline carbon stock change in shrub biomass for quantification unit *i* in year *t* – *x* (t CO2e/ha)

Shrub biomass carbon stock change in the project scenario is quantified as:

$$\Delta C_{SHRUB,wp,t} = \sum_{i=1}^{n} \left(\overline{\Delta C_{SHRUB,wp,i,t}} - \overline{\Delta C_{SHRUB,wp,i,t-x}}\right) \times \frac{1}{x} \times A_i \tag{51}$$

Where:

$\overline{\Delta C_{SHRUB,wp,i,t}}$ = Areal mean project scenario carbon stock change in shrub biomass for quantification unit *i* in year *t* (t CO2e/ha)

$\overline{\Delta C_{SHRUB,wp,i,t-x}}$ = Areal mean project scenario carbon stock change in shrub biomass for quantification unit *i* in year *t* – *x* (t CO2e/ha)

8.5.2 Fossil Fuel Combustion Emission Reductions ($\Delta CO2\_ff_t$)

GHG emission reductions from fossil fuel combustion are quantified as:

$$\Delta CO2\_ff_t = \sum_{i=1}^{n} \left(\overline{CO2\_ff_{bsl,i,t}} - \overline{CO2\_ff_{wp,i,t}}\right) \times A_i \tag{52}$$

Where:

$\overline{CO2\_ff_{bsl,i,t}}$ = Areal mean GHG emissions from fossil fuel combustion in the baseline scenario for quantification unit *i* in year *t* (t CO2e/ha)

$\overline{CO2\_ff_{wp,i,t}}$ = Areal mean GHG emissions from fossil fuel combustion in the project scenario for quantification unit *i* in year *t* (t CO2e/ha)

8.5.3 Liming Emission Reductions ($\Delta CO2\_lime_t$)

GHG emission reductions from liming are quantified as:

$$\Delta CO2\_lime_t = \sum_{i=1}^{n}\left(\overline{CO2\_lime_{bsl,i,t}} - \overline{CO2\_lime_{wp,i,t}}\right) \times A_i \tag{53}$$

Where:

$\overline{CO2\_lime_{bsl,i,t}}$ = Areal mean GHG emissions from liming in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$\overline{CO2\_lime_{wp,i,t}}$ = Areal mean GHG emissions from liming in the project scenario for quantification unit *i* in year *t* (t CO_2e/ha)

8.5.4 Methane Emission Reductions ($\Delta CH4_t$)

Methane emission reductions from the SOC pool are quantified as:

$$\Delta CH4\_soil_t = \sum_{i=1}^{n}\left(\overline{CH4\_soil_{bsl,i,t}} - \overline{CH4\_soil_{wp,i,t}}\right) \times A_i \tag{54}$$

Where:

$\overline{CH4\_soil_{bsl,i,t}}$ = Areal mean methane emissions from SOC pool in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$\overline{CH4\_soil_{wp,i,t}}$ = Areal mean methane emissions from SOC pool in the project scenario for quantification unit *i* in year *t* (t CO_2e/ha)

Methane emission reductions from livestock enteric fermentation are quantified as:

$$\Delta CH4\_ent_t = \sum_{i=1}^{n}\left(\overline{CH4\_ent_{bsl,i,t}} - \overline{CH4\_ent_{p,i,t}}\right) \times A_i \tag{55}$$

Where:

$\overline{CH4\_ent_{bsl,i,t}}$ = Areal mean methane emissions from livestock enteric fermentation in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$\overline{CH4\_ent_{wp,i,t}}$ = Areal mean methane emissions from livestock enteric fermentation in the project scenario for quantification unit *i* in year *t* (t CO_2e/ha)

Methane emission reductions from manure deposition are quantified as:

$$\Delta CH4\_md_t = \sum_{i=1}^{n}\left(\overline{CH4\_md_{bsl,i,t}} - \overline{CH4\_md_{wp,i,t}}\right) \times A_i \tag{56}$$

Where:

$\overline{CH4\_md_{bsl,i,t}}$ = Areal mean methane emissions from manure deposition in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$\overline{CH4\_md_{wp,i,t}}$ = Areal mean methane emissions from manure deposition in the project scenario for quantification unit *i* in year *t* (t CO_2e/ha)

Methane emission reductions from avoided or reduced biomass burning are quantified as:

$$\Delta CH4\_bb_t = \sum_{i=1}^{n} \left(\overline{CH4\_bb_{bsl,i,t}} - \overline{CH4\_bb_{wp,i,t}}\right) \times A_i \tag{57}$$

Where:

$\overline{CH4\_bb_{bsl,i,t}}$ = Areal mean methane emissions from biomass burning in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$\overline{CH4\_bb_{wp,i,t}}$ = Areal mean methane emissions from biomass burning in the project scenario for quantification unit *i* in year *t* (t CO_2e/ha)

8.5.5 Nitrous Oxide Emission Reductions ($\Delta N2O_t$)

Nitrous oxide emission reductions from nitrification/denitrification are quantified as:

$$\Delta N2O\_soil_t = \sum_{i=1}^{n} \left(\overline{N2O\_soil_{bsl,i,t}} - \overline{N2O\_soil_{wp,i,t}}\right) \times A_i \tag{58}$$

Where:

$\overline{N2O\_soil_{bsl,i,t}}$ = Areal mean nitrous oxide emissions from nitrogen inputs to soils in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$\overline{N2O\_soil_{wp,i,t}}$ = Areal mean nitrous oxide emissions from nitrogen inputs to soils in the project scenario for quantification unit *i* in year *t* (t CO_2e/ha)

Nitrous oxide emission reductions from biomass burning are quantified as:

$$\Delta N2O\_bb_t = \sum_{i=1}^{n} \left(\overline{N2O\_bb_{bsl,i,t}} - \overline{N2O\_bb_{wp,i,t}}\right) \times A_i \tag{59}$$

Where:

$\overline{N2O\_bb_{bsl,i,t}}$ = Nitrous oxide emissions from biomass burning in the baseline scenario for quantification unit *i* in year *t* (t CO_2e/ha)

$\overline{N2O\_bb_{wp,i,t}}$ = Nitrous oxide emissions from biomass burning in the project scenario for quantification unit *i* in year *t* (t CO_2e/ha)

8.6 Uncertainty

Uncertainty deductions are estimated separately for each GHG source within a project. Deductions are based on an estimate of the total error of the project's calculated reductions and removals for that source over a given verification period. Key sources of uncertainty that contribute to this error differ for each quantification approach. This section details these sources of error and methods to estimate such errors for use in an uncertainty assessment and calculation of the required uncertainty deduction.

Uncertainty guidance provided here assumes that all soil sampling/analysis and modeling occurs on a point basis. In other words, the model is run in a manner to represent a single point in space at which initial soil data and management data have been collected, and uncertainty is calculated by combining estimates of sampling, modeling, and measurement error based on the design chosen to select the points. Alternative approaches (e.g., modeling on an areal basis) are considered a deviation and project proponents must demonstrate that such approaches will not negatively impact the conservativeness of reduction and removal estimates per the most recent version of the *VCS Standard*.[53]

Across quantification approaches, a key source of error is sampling error, which emerges from only being able to measure/model a portion of the total project area. Appropriate estimates of this source of error are specific to the sample design employed. Per Section 8.2.1, this methodology requires that stratified random sampling is used. Strata should be based on physical and management factors that minimize within-strata variability. Individual sample points are allocated randomly within those strata on a proportional basis by area.

The remainder of this section is based on a simplified example of a stratified random sampling design in which the entire project is divided into strata and points within those strata are placed using simple random sampling with replacement. Examples of additional uncertainty calculations using a multi-stage design potentially applicable in grouped project scenarios are available in Appendix 6. Equations here and in Appendix 6 are provided as examples for possible sample designs expected to be used in projects developed under this methodology. Where a project proponent elects to use an alternative design via a methodology deviation, they must provide a similar demonstration of uncertainty calculations that consider the same sources of error identified here and that are appropriate to the chosen design.

8.6.1 Quantification Approach 1

Quantification Approach 1 is a measure and model approach in which a biogeochemical model is used to simulate changes in SOC stocks and GHG fluxes over a given time period in both the project and baseline scenarios. Initial measures of SOC are taken at the project start[54] for use within the model. SOC is periodically remeasured throughout the project period to true-up modeled estimates of SOC stock changes. Key sources of error accounted for under Quantification Approach 1 include:

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[53] Section 3.20 in the VCS Standard, v4.7.

[54] Initial measurements of SOC may be conducted at $t = 0$ or (back-) modeled to $t = 0$ from measurements collected within ±5 years of $t = 0$.

- **Model prediction error** resulting from uncertainty in model parameters or model structural errors (i.e., inaccurate representation of actual biogeochemical processes). Model prediction error is calculated using independent statistical validation datasets per the processes outlined in *VMD0053*. Alternatively, project proponents may account for model prediction error by calibrating models to include parameter uncertainty (e.g., a Bayesian implementation of the model) and using the Monte Carlo (MC) simulation or error propagation approach detailed below.
- **Sampling error** resulting from measuring/modeling only a portion of the project area. Estimates of sampling error are contingent on the sampling design employed by the project proponent.
- **Measurement error** of model inputs (see Table 6), including initial SOC content, bulk density, soil texture, and management data, where applicable. In many cases, the impact of these measurement errors on the error of estimated reductions and removals is assumed to be captured in model prediction error and/or sampling error (see Section 8.6.1.2.2 for additional details). Where alternative approaches for measuring SOC content, such as soil spectroscopy techniques, are used, procedures for estimating measurement error of these techniques as outlined in Appendix 6 must be followed. In this case, MC simulation is required unless it is demonstrated that such errors have a de minimis effect on model estimates of reductions and removals.

For each carbon pool or GHG flux, these sources of error are estimated separately and then combined to estimate a single uncertainty deduction for that carbon pool or GHG flux across the entire project. Two approaches are eligible to estimate the uncertainty:

1) Analytical calculation of error propagation; or
2) Monte Carlo (MC) simulation.

8.6.1.1 Analytical Calculation of Error Propagation

In this approach, the various sources of error outlined above are independently estimated for each GHG source or carbon pool • that results in a reduction or removal (e.g., SOC, N_2O). The estimated errors are then combined to provide an estimate of the total variance of the areal mean emission reductions and removals across the project for each source in each verification period ($s^2_{\Delta\bullet,t}$). This is used to determine an appropriate uncertainty deduction.

8.6.1.1.1 Model Prediction Error

Model prediction error includes model structural error (i.e., parameter uncertainty) and any errors related to model data inputs (e.g., inaccuracy of source for soil texture data), which result in incorrect estimation of a flux or change in stock in either the project or baseline scenarios or both. Model prediction error is quantified by using a statistical validation dataset that includes ground-truth measurements of stock changes or fluxes for the baseline and project scenario practices. Differences between these ground-truth measurements and model simulations of the same locations/practices are calculated, and assuming the model is unbiased, model prediction error is captured by the variance of these errors.

The ideal statistical validation dataset would come from controlled experimental field trials in which practices that simulate a project scenario are used in one part of the field and practices that simulate a baseline scenario are used in another part of the same field. Then, errors of the project minus baseline emissions of a certain gas or pool, $\Delta\bullet$, are computed directly at each site *i* using $error_{\Delta\cdot,i} = \widehat{\Delta\bullet}_i - \Delta\bullet_i$. The model uncertainty is estimated as the variance of $error_{\Delta\bullet}$, across all sites in the statistical validation dataset. Statistical validation data come from experiments that range in duration from a few years to many decades, and model prediction error at each point is derived from simulations that match the durations of those experiments. This means that these errors necessarily represent the accumulated model error over varying time intervals. When estimating model prediction error for verification, model error from a single verification period – which may range from one to five years – is required and is likely to be smaller than the raw mean squared statistical validation error.

For verification periods shorter than the median length of experiments in the statistical validation dataset, a single mixed-duration estimate of model prediction error is conservative and acceptable to use at verification. For example, where a model is validated against a dataset containing experiments with lengths of 2, 2, 3, 5, 9, and 48 years, the error from this statistical validation dataset may be applied to any simulation of length four years (the median length of experiments in the dataset) or shorter.

Where insufficient data are available to use the approach described above, quantification of model error may be split into two separate tasks:

1) Model predictions and ground truth measurements may be used to estimate typical errors of the prediction of reductions and removals in one scenario (e.g., just the project scenario), and
2) The correlation of errors between project and baseline scenarios may be estimated from a more limited number of side-by-side field trials such as those described above.

Assuming that the variance of the model prediction is the same in the project and baseline scenarios (i.e., $s^2_{model,\bullet,wp} = s^2_{model,\bullet,bsl}$ which is denoted by $s^2_{model,\bullet}$), then:

$$s^2_{model,\Delta\bullet} = s^2\left(\widehat{\Delta\bullet}_{bsl} - \widehat{\Delta\bullet}_{pr}\right) = 2\left[s^2_{model,\bullet} - cov(\widehat{\Delta\bullet}_{wp}, \widehat{\Delta\bullet}_{bsl})\right] \quad (60)$$

Where:

$s^2_{model,\Delta\bullet}$ = Variance of modeled estimates of emission reductions in gas or pool • (t CO_2e/ha)^2

$\widehat{\Delta\bullet}_{bsl}$ = Modeled estimate of change in emission reductions in gas or pool • in the baseline scenario (t CO_2e)

$\widehat{\Delta\bullet}_{wp}$ = Modeled estimate of change in emission reductions in gas or pool • in the project scenario (t CO_2e)

$s^2_{model,\bullet}$ = Estimated variance of errors made by model prediction of emissions in gas or pool • (estimated from measurements in fields that need not be side-by-side trials with baseline and project scenarios) (t CO_2e/ha)^2

By writing $cov(\widehat{\Delta\bullet}_{wp}, \widehat{\Delta\bullet}_{bsl})$ in terms of a correlation coefficient:

$$\rho = \frac{cov(\widehat{\Delta\bullet}_{wp}, \widehat{\Delta\bullet}_{bsl})}{\sqrt{(s^2_{model,\bullet\, wp})(s^2_{model,\bullet\, bsl})}} \qquad (61)$$

Then:

$$s^2_{model,\Delta\bullet} = 2\, s^2_{model,\bullet}\, (1-\rho)$$

Where:

ρ = Correlation of errors in project and baseline scenario pairs (estimated from side-by-side field trials of baseline and project scenarios)

Note – see parameter tables in Section 9.2 for derivation of $\bar{\Delta}_{\bullet,t}$ *and* $\bar{\bullet}_t$

Because side-by-side trials are rare, ρ is estimated from fewer data points than $s^2_{model,\bullet}$. In the initial stages of a project, it is expected that the datasets used to estimate model prediction error will be from peer-reviewed publications or readily available benchmark datasets that meet the requirements outlined in Section 5.2.3 of *VMD0053*. As the project proceeds and SOC stocks in the project scenario are periodically remeasured, data from true-up sampling should be added to the model calibration/validation dataset to update the estimate of model prediction error for the SOC pool (see Section 8.6.1.3 for additional details). An updated model validation report (MVR) must be re-submitted for assessment by an independent modeling expert. For other GHG fluxes that are modeled under Quantification Approach 1 (e.g., N_2O, CH_4), model prediction error should continue to be based on the use of statistical validation datasets but may be updated as new datasets become available that match the criteria outlined in *VMD0053*.

Within a project, it is possible that different model prediction errors may be applicable to different portions of the project area. For example, a project may include areas where a cover crop is being implemented, and others where reduced tillage is being implemented, representing two different project scenarios for which model prediction error may differ. Similarly, a project may span a geographic area with varied climate and/or soil types across which model prediction error may differ. In such cases, different model prediction error terms most appropriate to a given quantification unit should be selected, and an aggregate estimate of model prediction error across the entire project must be determined using an estimator appropriate to the design.

8.6.1.1.2 Model Input and Measurement Error

The ALM data used as model inputs may be an important source of error where details of such activities are not well known. However, as projects are expected to follow the data collection procedures outlined in Box 1 to determine ALM activities across the entire project area, this source of error is assumed to be sufficiently minor. Similarly, uncertainty related to estimation of area is considered to be negligible provided that GIS boundaries of the project area are accurately delineated and that the necessary QA/QC procedures to remove irrelevant features (e.g., streams, pavement, areas not under improved management) outlined in the parameter table for A_i are followed.

Measurement error of physical properties (e.g., precipitation, soil texture) used as model inputs may also be a source of error, although this has generally been found to be less significant than model structural error (Ogle et al., 2010; Peltoniemi et al., 2006). Provided that measurement errors in model inputs translate to measurement errors in model predictions that are uncorrelated across sample points, these errors are automatically captured by the estimate of sample error discussed below.[55] Similarly, for inputs such as precipitation, which are the same across baseline and project scenarios and for which estimates are retrieved for a given point from the same data source (e.g., GIS data products, digital soil maps), the influence of such measurement error on estimates of reductions and removals is captured in the estimate of model prediction error generated through model calibration/validation procedures. These procedures are described in the preceding section and in *VMD0053*. Remeasurement and true-up provide additional opportunities to refine these error estimates.

Where soil spectroscopy tools are used in place of conventional analytical techniques to determine SOC content at sampling points, it must not be assumed that measurement error from such methods is automatically captured in the estimate of model prediction error or that the impact of such errors is negligible. Soil spectroscopy methods may have high measurement error under different circumstances and may be biased (i.e., error differs depending on the carbon content of the sample under consideration and the coverage of datasets used to calibrate/validate the soil spectroscopy model). Biogeochemical models are sensitive to initial starting SOC content, meaning error in estimates will have a non-linear impact on model simulations of both the baseline and project scenarios. Therefore, where soil spectroscopy is used to determine SOC content data for use as an input to biogeochemical models, the MC simulation approach must be used, unless project proponents demonstrate that measurement error from the tool used is unbiased and has a de minimis impact on model simulations.

Where uncertainty of ALM data or measurement error of other input data types is considered to have an impact on modeled estimates of reductions and removals despite use of best practices in data collection, the MC simulation method for error propagation should be used.

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[55] See, for example, Cochran (1977, p. 382); de Gruijter et al. (2006, p. 82); Som (1995, p. 438)

8.6.1.1.3 Sampling Error

Sampling error derives from only measuring or modeling a subset of the entire project area, resulting in a potentially inaccurate estimate of the true variance of a GHG flux or carbon stock change. Sampling error is determined by calculating the approximate standard error of GHG fluxes or carbon stock changes as simulated by the model for a given verification period. The uncertainty estimator used must be based on the sampling design employed. All examples provided here assume that the default approach of measuring/modeling on a point basis is employed. Where alternative approaches are proposed via a methodology deviation, project proponents must provide evidence that the design is unbiased and must document use of the correct uncertainty estimator to capture sampling error (see also Section 8.2.1).

This section is based on a stratified random sampling design in which the entire project is divided into strata and points are randomly allocated (with replacement) within the strata. Soil samples are collected at these points and the model is run. Formulae for uncertainty estimators are drawn from Som (1995, Ch. 10). Additional examples are provided in Appendix 6. As stated in Section 8.2.1.2, 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. This information feeds into Equation (62) for the parameters stratum identifier (*h*), area of stratum (A_h), and sample point identifier (*ip*).

$$s^2_{sampling,\Delta\bullet,t} = \sum_{h=1}^{H} s^2_{sampling,\Delta\bullet,h,t} \tag{62}$$

Where:

$$s^2_{sampling,\Delta\bullet,h,t} = \frac{A_h^2}{n_h(n_h-1)} \sum_{ip=1}^{n_h} \left(\Delta\bullet_{h,ip,t} - \overline{\Delta\bullet_{h,t}}\right)^2$$

and:

$s^2_{sampling,\Delta\bullet,t}$ = Variance of reductions and removals in gas or pool • due to sampling error at time *t* across the entire project area (t $CO_2e)^2$

$s^2_{sampling,\Delta\bullet,h,t}$ = Variance of reductions and removals in gas or pool • within stratum *h* due to sampling error at time *t* (t $CO_2e)^2$

$\overline{\Delta\bullet_{h,t}}$ = Areal mean reductions and removals in gas or pool • in stratum *h* at time *t*, computed as the mean across the sample points in stratum *h* (t CO_2e/ha)

$\Delta\bullet_{h,ip,t}$ = Estimated reductions and removals of gas or pool • on an area basis in year *t* in stratum *h* at point *ip* (t CO_2e/ha)

h = 1, …, *H* strata across the entire project area

ip = 1, …, n_h sample points within stratum *h*

A_h = Area of stratum *h*

8.6.1.1.4 Combined Sample and Model Error

To incorporate model errors, assume that they are uncorrelated with the input data in the sample and are independent across samples. Then, the variance of $\overline{\Delta \bullet}_t$ incorporating sample uncertainty and model prediction uncertainty is estimated by combining the variance estimates of both error sources divided by the square of the total project area (Cochran, 1977 Eq. 13.39; Som, 1995 Eq. 25.10). Note that only the estimate of sampling error is divided by the square of the project area in this example as it is presumed that model prediction error has already been determined on an area basis per Equations (60)–(61)~~(61)~~.

$$s^2_{\overline{\Delta\bullet},t} = \frac{s^2_{sampling,\Delta\bullet,t}}{A^2} + s^2_{model} \tag{63}$$

Where:

$s^2_{\overline{\Delta\bullet},t}$ = Variance of the estimate of mean reductions and removals from gas or pool • at time *t* (t CO_2e/ha)^2

s^2_{model} = Variance of the estimate of reductions and removals in gas or pool • due to model prediction error (t CO_2e/ha)^2

A = Total project area

Lastly, s^2_{model} is an estimate of average variance of model prediction errors across the project and is estimated using an estimator appropriate to the project sampling design. In this example, it is assumed that the model prediction error value for each stratum is selected based on the specific project and baseline scenarios being implemented in that stratum and as such s^2_{model} is estimated using an area-weighted uncertainty estimator.

$$s^2_{model} = \sum_{h=1}^{H} \frac{A_h^2}{A^2} s^2_{model,h} \tag{64}$$

8.6.1.2 Monte Carlo Simulation

In addition to the analytical error propagation method detailed in Section 8.6.1.1, a Monte Carlo (MC) simulation method may be used for uncertainty estimation. MC simulation methods are commonly used in Bayesian analyses, which have gained popularity as a framework for estimating uncertainty of outputs from process-based biogeochemical models of soils and agroecosystems and estimating the uncertainty of biogeochemical model predictions (Gurung et al., 2020; Kennedy & O'Hagan, 2001). MC simulation methods are suitable for nonlinear, deterministic, process-based biogeochemical models (e.g., DayCent, DNDC). Unlike the analytical error propagation method, the MC method more easily addresses key dependencies in underlying data (such as correlation between model parameters) and asymmetric error distributions (such as non-negative or highly skewed distributions). The MC method is used in the USDA's approach for estimating emissions at the farm scale (Eve et al., 2014) and in the US

National GHG Inventory (US EPA, 2021). The approach is also described in peer-reviewed literature (Gurung et al., 2020; Ogle et al., 2007, 2010).

For each sample point, a set of L random samples (total number of MC simulations) is drawn from a posterior predictive distribution (PPD) produced by the model. Within each quantification unit, the total set of PPDs across all points are then aggregated to determine the areal mean unbiased estimator of the reduction and removal estimates being evaluated and the uncertainty of those estimates. Random samples may also be taken from probability distribution functions of model input data, particularly where those inputs have measurement error that is not accounted for in the model validation process.

To generate a PPD, Bayesian calibration methods must be used to estimate model parameters as probability distribution functions (as opposed to single values). To ensure parity with the analytical error propagation method detailed in Section 8.6.1.1, these probability distribution functions of model parameters must be determined per the model calibration/validation guidance in *VMD0053* using external datasets representative of the project area and activities or, in the case of SOC, using remeasured project SOC stocks (see Section 8.6.1.3). In other words, the likelihood function from which the PPD is sampled must be based on the same dataset against which the model is statistically validated. Steps to calibrate and validate a model for use with the MC uncertainty propagation method must be documented in a model validation report following the guidance in *VMD0053*.

Since many biogeochemical models include dozens of parameters, not all parameters are expected to be calibrated as probability distribution functions. Instead, a more limited number of parameters may be used for MC simulation, for instance identified through sensitivity analysis. In the simplest implementation, a single parameter representing residual model prediction error may be used. In such cases, MC simulation is implemented using a “meta-model” that represents uncertainty in the chosen set of parameters but does not necessarily require direct modification of model source code. Kennedy and O’Hagan (2001) provide additional detail on relevant calibration methods and Gurung et al. (2020) provide an example of such methods being specifically implemented for a soil biogeochemical model. Gelman et al. (2014) is a useful reference on Bayesian statistical methods and provides additional detail on definitions of PPDs and valid methods to generate them.

The notation in this section is different than in previous sections, aligning with notation commonly used in Bayesian statistics. Key differences include:

- The observed outcome of interest (i.e., reductions and removals) is denoted as y, which is commonly used in statistics to denote outcomes.
- MC draws of model-predicted reductions and removals are denoted as $\tilde{y}$. The tilde serves as a reminder that $\tilde{y}$ is a model prediction drawn from a PPD (following standard notation in Gelman et al., 2014; Hoff, 2009) due to the use of Bayesian calibration (Kennedy & O’Hagan, 2001).

- Total reductions and removals and areal mean reductions and removals are denoted as τ and μ, respectively, in keeping with Thompson (2012). The use of lowercase Greek letters is also a reminder that the estimand of interest (true total and areal mean reductions and removals) cannot be directly observed due to measurement error.
- The notation in this section suppresses notation for verification period *t* for convenience and to avoid confusion with the Greek character τ (total reductions and removals) which is used throughout.
- *Var* is used in place of s^2 in multiple locations to signify variance to more easily match Equation (68)~~(68)~~, which describes how variance is broken down into sampling and modeling error.

8.6.1.2.1 Combined Sample and Model Error

For a particular time period and GHG emission source, the estimand, or target parameter of interest, is the true total reductions and removals across the entire project, denoted as τ, in tonnes of carbon dioxide equivalent (t CO_2e). The estimate of τ produced through MC simulation is denoted by $\hat{\tau}$. Similarly, the areal mean reductions and removals is denoted by μ (equivalent to $\Delta \bullet_t$) in t CO_2e/ha. Estimates of μ are denoted as $\hat{\mu}$. Since model prediction error is implicitly incorporated into the MC simulations through parameter uncertainty, these estimates may then be used to estimate sampling and model prediction error based on the realized sample *s* and the sampling design employed. Here, an example of this process is provided, using the same stratified random sample design demonstrated in Section 8.6.1. Additional examples are provided in Appendix 6.

First, to generate an estimate ($\hat{\tau}$) of τ, GHG emissions are simulated under the baseline and project scenarios multiple times at each sample point, indexed by l = 1, …, L. The reductions and removals at each point are then calculated as the difference between predicted GHG emissions under baseline and project scenarios. These estimates are used to produce an estimate of reductions and removals ($\tilde{y}$) at each point, similarly indexed by l following Equation (65)~~(65)~~ below.

$$\tilde{y}_{h,ip,l} = \tilde{z}_{bsl,h,ip,l} - \tilde{z}_{wp,h,ip,l} \tag{65}$$

Where:

$\tilde{y}_{h,ip,l}$ = Predicted reductions and removals on an area basis for point *i* in stratum *h* and MC simulation l (t CO_2e/ha)

$\tilde{z}_{bsl,h,ip,l}$ = Predicted GHG emissions in the baseline scenario on an area basis for point *ip* in stratum *h* and MC simulation l (t CO_2e/ha)

$\tilde{z}_{wp,h,ip,l}$ = Predicted GHG emissions in the project scenario on an area basis for point *ip* in stratum *h* and MC simulation l (t CO_2e/ha)

l = 1, …, *L* MC simulations

Note – notation for the source of emissions and time period is suppressed. The sign convention is that $\tilde{z}_{bsl,h,ip,l}$ *is emissions to the atmosphere in the baseline scenario. Thus, for the SOC pool,* $\tilde{z}_{bsl,h,ip,l}$ *is −1 times the predicted temporal change in SOC stocks in the baseline scenario. Similarly,* $\tilde{z}_{wp,h,ip,l}$ *is −1 times the predicted temporal change in the project scenario.*

The total set of L estimates of $\tilde{y}$ are then used to produce $\hat{t}$ and $\hat{\mu}$, according to Equation (66)~~(66)~~.

$$\hat{\mu} = \frac{\hat{\tau}}{A} \tag{66}$$

Where:

$$\hat{\tau} = \sum_{h=1}^{H} \hat{\tau}_h$$

$$\hat{\tau}_h = \frac{A_h}{n_h L} \sum_{ip=1}^{n_h} \left(\sum_{l=1}^{L} \tilde{y}_{h,ip,l} \right)$$

and:

$\hat{\tau}$ = Monte Carlo estimate (MC mean) of total reductions and removals for a given source across the whole project area (t CO_2e)

$\hat{\mu}$ = Areal mean unbiased estimator of reductions and removals for gas or pool • in year *t* (t CO_2e/ha)

$\hat{\tau}_h$ = Monte Carlo estimate (MC mean) of reductions and removals for a given source within stratum *h* (t CO_2e)

The total uncertainty is then decomposed into two components, sampling and modeling uncertainty. Using standard variance decomposition (i.e., the law of total variance) following Del Grosso et al. (2010), the total variance is decomposed according to Equation (67)~~(67)~~.

$$\mathrm{Var}(\hat{\tau}) = \mathbb{E}[\mathrm{Var}(\hat{\tau}|\boldsymbol{s})] + \mathrm{Var}(\mathbb{E}[\hat{\tau}|\boldsymbol{s}]) \tag{67}$$

Where:

$\mathbb{E}[\mathrm{Var}(\hat{\tau}|\boldsymbol{s})]$ = Estimate of model uncertainty (i.e., expectation of the conditional variance given the sample design)

$\mathrm{Var}(\mathbb{E}[\hat{\tau}|\boldsymbol{s}])$ = Estimate of uncertainty due to sampling design (i.e., variance of the conditional expectation)

s = The realized sample, selected using the sample design

For the stratified random sampling design used in this example, the variance components are estimated according to the following system of equations. Note that these are similar in form to those in Section 8.6.1 and are derived from Som (1995, Ch. 10).

$$\widehat{Var}(\hat{\tau}) = s^2_{sampling} + s^2_{model} = \left\{\sum_{h=1}^{H} s^2_{sampling,h}\right\} + s^2_{model} \tag{68}$$

Where:

$$s^2_{sampling,h} = \frac{A_h^2}{n_h(n_h - 1)} \sum_{ip=1}^{n_h} \left(\hat{y}_{h,ip} - \hat{\mu}_h\right)^2$$

$$\hat{y}_{h,ip} = \frac{1}{L} \sum_{l=1}^{L} \tilde{y}_{h,ip,l}$$

$$\hat{\mu}_h = \frac{\hat{\tau}_h}{A_h}$$

and:

$$s^2_{model} = \frac{1}{L-1} \sum_{l=1}^{L} (\tilde{\tau}_l - \hat{\tau})^2$$

$$\tilde{\tau}_l = \sum_{h=1}^{H} \tilde{\tau}_{h,l}$$

$$\tilde{\tau}_{h,l} = \frac{A_h}{n_h} \sum_{ip=1}^{n_h} \tilde{y}_{h,ip,l}$$

and:

$s^2_{sampling}$	=	Variance of reductions and removals in gas or pool • due to sampling error at time *t* (notation suppressed) across the entire project area (t CO_2e)^2
$s^2_{sampling,h}$	=	Variance of reductions and removals in gas or pool • within stratum *h* due to sampling error at time *t* (notation suppressed) (t CO_2e)^2
$\tilde{\tau}_l$	=	Total reductions and removals for the lth MC simulation of the project (t CO_2e)
$\tilde{\tau}_{hl}$	=	Total reductions and removals in stratum *h* for the lth MC simulation (t CO_2e)
$\hat{y}_{h,ip}$	=	MC estimate of areal mean reductions and removals for point *ip* in stratum *h* (t CO_2e/ha)
$\hat{\mu}_h$	=	MC estimate of areal mean reductions and removals in stratum *h* (t CO_2e/ha)

Last, the variance of the mean reductions and removals $\left(\widehat{\mathrm{Var}}(\hat{\mu})\right)$ is obtained by dividing $\widehat{\mathrm{Var}}(\hat{\tau})$ by the square of the total project area (A^2).

$$\widehat{Var}(\hat{\mu}) = s^2_{\Delta\bullet} = \frac{s^2_{sampling} + s^2_{model}}{A^2} \tag{69}$$

In Equations (68)~~(68)~~–(69), the sampling variance may be calculated separately for each stratum and then summed together, because the sampled points are selected independently in different strata (see Theorems 5.1 and 5.2 of Cochran, 1977, pp. 91–92). In contrast, model prediction errors may not be independent across strata due to shared calibration parameters. Thus, estimation of model variance must not be split across strata and is instead estimated across the entire project area. Unlike in Equation (63), the model prediction error (s^2_{model}) must be divided by the square of the project area because in this example it is estimated on the basis of total reductions and removals achieved across the entire project area.

8.6.1.2.2 Monte Carlo Propagation of Model Input Error

Monte Carlo error propagation methods may be used in some cases to propagate model input errors alone. In Section 8.6.1.2, these errors are identified as being otherwise captured in estimates of sample or model prediction error. However, in some circumstances, such as when land management data are uncertain or soil spectroscopy tools are used to measure initial SOC, these errors may not be captured in those terms. MC error propagation is appropriate in such cases and need not require recalibration of soil model parameters. In such cases, the measurement errors are propagated to the sampling error term, which should be determined according to the procedures outlined in Equations (65)~~(65)~~–(68)~~(68)~~ that relate to sampling error. For example, MC simulations would entail sampling from a PPD of estimated SOC content for a given point based on a chosen soil spectroscopy method (see Appendix 4 for additional details), and those values would be used to initialize the process-based model. Model prediction error may be determined using either the analytical error propagation method or the MC simulation method and is added to the estimate of sampling error to provide an estimate of the total uncertainty for a given emission reduction or removal.

8.6.1.2.3 Monte Carlo Error

The accuracy of the MC estimates depends on the number of independent MC draws. Where MC draws use a Markov Chain Monte Carlo (MCMC) algorithm such as the No-U-Turn Sampler implemented in Stan (Carpenter et al., 2017), samples may contain some autocorrelation and thus the MC error depends on an effective sample size that is smaller than the initial number of chosen draws. The MC error (errors due to using a finite number of MC draws) decreases with increasing number of MC draws. According to Gelman et al. (2014, p. 267), the contribution of MC error to MC estimates of standard error is $\sqrt{1 + 1/L}$. For L = 100 independent MC draws, MC error would inflate the standard error by a factor of only 1.005, implying that the MC error adds almost nothing to the uncertainty estimation. More than 100 simulations may add numerical stability to estimates, particularly for the percentile summaries. Gelman et al. (2014)

suggest a choice of *L* between 100 and 2000. A value between 500 and 1000 is suggested to balance accuracy and computing power demand.

8.6.1.3 Remeasurement, Model True-Up and Cumulative Modeling

As outlined in Section 8.3, SOC stocks must be directly remeasured every five years in the project scenario. These data are used to re-estimate model prediction error and/or recalibrate the model in relation to measured SOC stocks. Since the purpose of remeasurement is improvement of the applied biogeochemical model over time, soil samples do not need to be taken from every project activity instance (i.e., field or management unit) at every remeasurement event. In consequence, the requirement to measure SOC stocks every five years or more frequently (see Section 8.1) does not apply at the project activity instance-level. The stratified random sampling strategy must be redefined as necessary to include changes in the project area (e.g., through the inclusion of new project activity instances). The sampling error associated with not sampling each project activity instance must be calculated accordingly.

Prior to remeasurement, model structural error during simulation of SOC stocks for initial model validation will be based ~~be based~~ on data from peer-reviewed publications and available datasets meeting the requirements detailed in Section 5.2.3 of *VMD0053*. Specifically, the model is used to simulate changes in stocks from a set of selected external datasets (i.e., field trials for which data have been previously collected). Following remeasurement (i.e., true-up sampling), data from external datasets and remeasurement within the project area are combined to create a new calibration/validation. If the project proponent so chooses, this dataset may be used to recalibrate model parameters (or parameter distributions in the case of Bayesian models) in an effort to improve model accuracy, although model recalibration is not required. Following remeasurement, project proponents must repeat model validation procedures outlined in VMD0053, submit an updated MVR for IME review and validation, and ~~34~~ update the model prediction error term used ~~in the~~to estimat~~ion~~e ~~of~~ the project uncertainty deduction.

Once the MVR is approved, project proponents should rerun model simulations for both the baseline and project scenarios from t_0 up to the present day and recalculate uncertainty deductions to be applied to future credit vintages. VCUs that have been issued in previous verifications will remain unchanged.

Figure 4a illustrates the interaction between:

- measurement (t_0) and remeasurement (t_1, t_2, t_3) campaigns,
- the timing for assessment of an updated MVR, and

- continuous onboarding of cohorts[56a] of project activity instances.

In Figure 4a, t_0 denotes initial measurement, t_1 and t_2 denote subsequent remeasurements, and "cohorts" refer to groups of activity instances added over time, which may be sampled individually or through joint campaigns.

The following scenarios, which all conform to *VM0042* requirements, are illustrated in Figure 4a:

A) Sequential cohorts with synchronized remeasurement:
  - Cohorts 1–3 are measured at entry (t_0), one per year.
  - t_1: conducted five years after Cohort 1's t_0, for all cohorts (1–3).
  - t_2: conducted five years after t_1, for all cohorts.

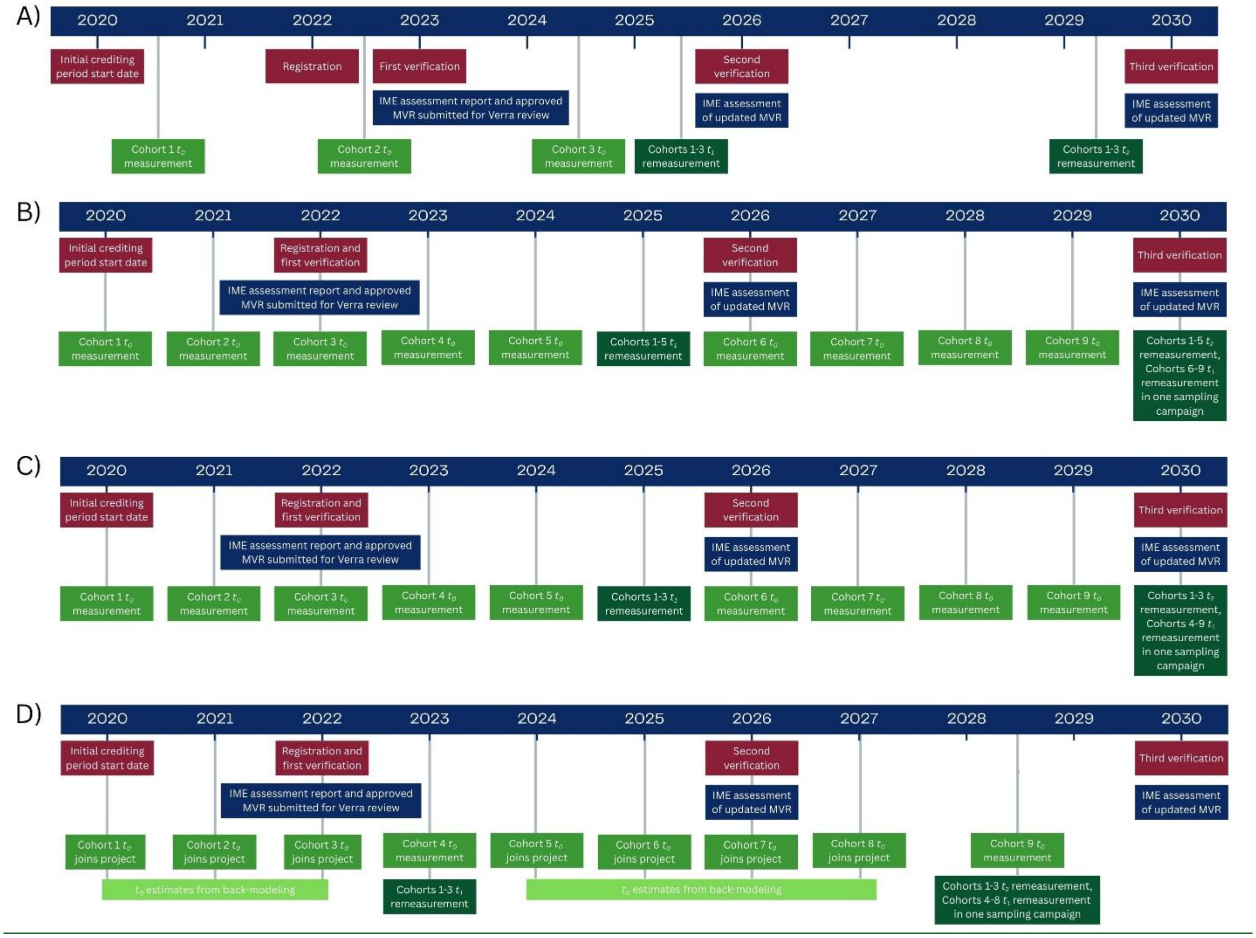
B) Sequential cohorts with staggered cohorts and joint sampling:
  - Cohorts 1–9 are measured at entry (t_0), one per year.
  - t_1 (Cohorts 1–5): conducted five years after Cohort 1's t_0.
  - Next campaign (joint): conducted five years after t_1 for Cohorts 1–5, to measure:
    - t_2 for Cohorts 1–5
    - t_1 for Cohorts 6–9

C) Delayed remeasurement for later cohorts:
  - Same approach as B with a difference for cohorts 4 and 5.
  - Difference:
    - Cohorts 4 and 5 are measured at entry (t_0) but remeasured later than the standard interval.
    - Their t_1 occurs after seven and six years, respectively (instead of shorter intervals of one or two years, under joint sampling).

D) Deferred initial sampling with back-modeling:
  - Cohorts 1–3 are not measured at entry; instead, back-modeling is used to estimate t_0.
  - When Cohort 4 joins, remeasurement campaign serves as:
    - t_0 for Cohort 4
    - t_1 for Cohorts 1–3
  - Back-modeling is used to estimate t_0 for Cohorts 5–8.
  - Later campaign (when Cohort 9 joins):
    - t_2 for Cohorts 1–3
    - t_1 for Cohorts 4–8
    - t_0 for Cohort 9

[56a] It is assumed that multiple project activity instances may be onboarded at different times during a monitoring period. The term cohort is therefore used to refer to all instances added to a project within a given year. This differs from the concept of a batch under the *VCS Standard, v5.0*, which refers to groups of instances added at a verification event and may include one or more cohorts.

Figure 4a. Interplay between adding project activity instances over time, remeasurement intervals, options for back-modeling, and updates to the MVR



8.6.2 Quantification Approach 2

Quantification Approach 2 is applicable for SOC stocks only. The baseline is represented by control sites that are linked to one or more project quantification units. The SOC stock difference and its uncertainty is calculated based on comparisons of control sites and paired project quantification units. Key sources of error accounted for under Quantification Approach 2 include:

- **Sampling error** resulting from measuring/modeling only a portion of the project area
- **Measurement error** of methods used to determine SOC stock equivalents (t CO_2e per unit area) at sample points. Where samples are collected using ESM approaches and analyzed using dry combustion via a lab with demonstrated proficiency and quality control (e.g., through participation in the North American Proficiency Testing

program[57]), these errors are assumed to be unbiased and negligible. Where alternative measurement approaches such as soil spectroscopy techniques are used, measurement error must be estimated and propagated through estimates of the total change in SOC.

These sources of error are estimated separately and then combined to estimate a single uncertainty deduction for SOC stocks across the entire project. Similar to Quantification Approach 1, an analytical error propagation or MC simulation method may be used. The MC simulation method is only applicable in cases where measurement error is deemed significant and must be propagated through calculations.

As in Section 8.6.1, an example is provided here based on the default stratified random sampling approach. In this example, each individual stratum is paired with an appropriately determined control site. Net SOC stock changes in the project scenario are determined by comparing net change in SOC in project sites against net change in baseline control sites over a given verification period *t*, determined through direct sampling and dry combustion analysis of soil samples collected at the beginning and end of period *t.* It is assumed that the same set of sample points are visited at both time points.

The total variance of the SOC stock change estimate is then determined using an area-weighted uncertainty estimator based on the variance of SOC stock change estimates in each stratum. Variance of SOC stock change estimates in each stratum are based on the combined variance of the estimates of change over time in a given verification period *t* for both the project and baseline scenarios. The covariance of these estimates is conservatively excluded as the baseline control sites and project sites are assumed to be independent. In these equations, Δ is used to signify reductions and removals in the SOC pool (i.e., project scenario SOC stocks minus baseline scenario SOC stocks) and changes in SOC stocks over time in both the baseline and project scenarios.

$$s^2_{\overline{\Delta SOC,t}} = \frac{1}{A^2}\sum_{1}^{n} s^2_{\Delta SOC,h,t} \tag{70}$$

Where:

$$s^2_{\Delta SOC,h,t} = s^2_{\Delta SOC,wp,h,t} + s^2_{\Delta SOC,bsl,h,t}$$

and:

$s^2_{\overline{\Delta SOC,t}}$ = Variance of the estimate of mean SOC stock changes in verification period *t* across the entire project area, calculated as the difference in net change between the project and baseline scenarios over period *t* (t CO_2e/ha)^2

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[57] Available at: https://www.naptprogram.org/

$s^2_{\Delta SOC,h,t}$ = Variance of the estimate of total SOC stock changes in verification period *t* in stratum *h*, calculated as the difference in net change between the project and baseline scenarios over period *t* (t CO_2e)^2

$s^2_{\Delta SOC,wp,h,t}$ = Variance of the estimate of total SOC stock changes in the project plots in verification period *t* in stratum *h*, calculated as the difference in SOC stocks at the beginning and end of period *t* (t CO_2e)^2

$s^2_{\Delta SOC,bsl,h,t}$ = Variance of the estimate of total SOC stock changes in baseline (control) plots paired with project stratum *h* in verification period *t*, calculated as the difference in SOC stocks at the beginning and end of period *t* (t CO_2e)^2

Note that the area-weighting in Equation (70)~~(70)~~ is based on the area of the project strata, not the baseline control sites with which they are paired.

Because the sample design for the project and baseline control plots may be different, the uncertainty estimator should match the sample design used in the project and baseline control plots. For example, the project area may be monitored using a staged design if there are a substantial number of quantification units (e.g., fields) in the project area. But the baseline control plots may be fewer, meaning they can all be monitored and do not require a staged design. In such cases, baseline and project areas should use different uncertainty estimators before estimating the combined uncertainty. This example presumes that within each stratum, sample points are similarly determined using simple random sampling with replacement for both baseline and project scenarios, so the estimator in both scenarios is the same.

Equation (71) provides an example for the project scenario. The variance of the estimate of the change is then a function of the variance and covariance of soil sampling results at both time points within verification period *t*. These time points are denoted as t_{final} and t_{start}, hereafter shortened to subscripts *f* and s.

$$s^2_{\Delta SOC,wp,h,t} = s^2_{SOC,wp,h,f} + s^2_{SOC,wp,h,s} - 2COV(SOC_{wp,h,f}\ ;\ SOC_{wp,h,s}) \qquad (71)$$

Where:

$$s^2_{SOC,wp,h,f} = \frac{A_h^2}{n_h(n_h-1)}\sum_{ip=1}^{n_h}\left(SOC_{wp,h,ip,f} - \overline{SOC}_{wp,h,f}\right)^2$$

$$s^2_{SOC,wp,h,s} = \frac{A_h^2}{n_h(n_h-1)}\sum_{ip=1}^{n_h}\left(SOC_{wp,h,ip,s} - \overline{SOC}_{wp,h,s}\right)^2$$

$$COV\left(SOC_{wp,h,f}\ ;\ SOC_{wp,h,s}\right) = \frac{A_h^2}{n_h(n_h-1)}\sum_{ip=1}^{n_h}\left(SOC_{wp,h,ip,s} - \overline{SOC}_{wp,h,s}\right)\left(SOC_{wp,h,ip,f} - \overline{SOC}_{wp,h,f}\right)$$

and:

$s^2_{SOC,wp,h,f}$ = Variance of the estimate of SOC stocks in the project scenario at t_{final} in stratum h (t CO_2e)^2

$s^2_{SOC,wp,h,s}$ = Variance of the estimate of SOC stocks in the project scenario at t_{start} in stratum h (t CO_2e)^2

$COV(SOC_{wp,h,f}\ ;\ SOC_{wp,h,s})$ = Covariance of estimates of SOC stocks at t_{final} and t_{start} in the project scenario in stratum h (t CO_2e)^2

$\overline{SOC}_{wp,h,f}$ = Mean estimate of SOC stocks across all points in the project scenario at t_{final} in stratum h (t CO_2e/ha)

$\overline{SOC}_{wp,h,s}$ = Mean estimate of SOC stocks across all points in the project scenario at t_{start} in stratum h (t CO_2e/ha)

$SOC_{wp,h,ip,f}$ = Estimated SOC stock on an area basis at point *ip* in the project scenario at t_{final} in stratum h (t CO_2e/ha)

$SOC_{wp,h,ip,s}$ = Estimated SOC stock on an area basis at point *ip* in the project scenario at t_{start} in stratum h (t CO_2e/ha)

8.6.2.1 Alternative SOC Measurement Methods

Projects may elect to use alternative measurement methods to determine SOC content at each sample point, such as Vis-NIR and MIR (see Appendix 4). Such methods may reduce sampling error by allowing for data collection at a greater number of points. However, they introduce error into the estimation of reductions and removals through the model used to estimate SOC based on reflectance/absorbance data from the chosen instrument. This error is handled using MC simulation methods similar to those in Quantification Approach 1. The value of SOC at each point is iteratively resampled *L* times from a PPD derived from a soil spectroscopy model calibrated and validated with an independent dataset appropriate to the project area. Alternatively, the project proponent may estimate the error of the spectroscopy model by selecting 10–15% of samples in the project, analyzing these samples using dry combustion methods, and comparing those results to the spectroscopy model predictions. See Appendix 4 for additional detail on how these models should be calibrated and statistically validated, as well as how PPDs should be developed where an MC simulation approach is applied.

In either case, uncertainty is estimated using a similar overall form as the procedures outlined in Equations (70)~~(70)~~ and (71), but the uncertainty estimators in Equation (71) for estimating uncertainty within an individual stratum are modified to include both sampling error and model error from the soil spectroscopy model. Equation (72)~~(72)~~ provides an example using the MC simulation approach for the project scenario in a given stratum *h*. Individual estimates of SOC content at each soil sampling point are sampled from a PPD *L* times and compared to the mean estimate of SOC across all *L* simulations to generate uncertainty estimates.

$$s^2_{\Delta SOC,wp,h,t} = s^2_{SOC,wp,h,f} + s^2_{SOC,wp,h,s} - 2COV(SOC_{wp,h,f}\ ;\ SOC_{wp,h,s}) \qquad (72)$$

The variance of an individual stratum is estimated as follows. The same equation form applies to time point s.

$$s^2_{SOC,wp,h,f} = s^2_{SOC,wp,h,f,sample} + s^2_{SOC,wp,h,f,model}$$

$$s^2_{SOC,wp,h,f,sample} = \frac{A_h^2}{n_h(n_h-1)} \sum_{ip=1}^{n_h} \left(SOC_{wp,h,ip,f} - \overline{SOC}_{wp,h,f}\right)^2$$

$$SOC_{wp,h,ip,f} = \frac{1}{L} \sum_{l=1}^{L} SOC_{wp,h,ip,f,l}$$

$$\overline{SOC}_{wp,h,f} = \frac{1}{A_h} \sum_{ip=1}^{n_h} SOC_{wp,h,ip,f}$$

$$s^2_{SOC,wp,h,f,model} = \frac{1}{L-1} \sum_{l=1}^{L} \left(SOC_{wp,f,l} - \overline{SOC}_{wp,f}\right)^2$$

$$SOC_{wp,f,l} = \sum_{h=1}^{H} SOC_{wp,h,f,l}$$

$$SOC_{wp,h,f,l} = \frac{A_h}{n_h} \sum_{ip=1}^{n_h} SOC_{wp,h,f,ip,l}$$

$$\overline{SOC}_{wp,f} = \frac{1}{L} \sum_{l=1}^{L} SOC_{wp,f,l}$$

$$\begin{aligned} &COV\left(SOC_{wp,h,f}\ ;\ SOC_{wp,h,s}\right) \\ &\qquad = \frac{1}{L} \sum_{l=1}^{L} \left\{ \frac{A_h^2}{n_h(n_h-1)} \sum_{ip=1}^{n_h} \left(SOC_{wp,h,ip,s,l} - \overline{SOC}_{wp,h,s}\right) \left(SOC_{wp,h,ip,f,l} \right.\right. \\ &\qquad \left.\left. - \overline{SOC}_{wp,h,f}\right) \right\} \end{aligned}$$

Where:

$s^2_{SOC,wp,h,f,sample}$ = Variance of the estimate of SOC stocks in the project scenario at t_{final} in stratum *h* attributable to sampling error (t CO_2e)^2

$s^2_{SOC,wp,h,f,model}$ = Variance of the estimate of SOC stocks in the project scenario at t_{final} in stratum *h* attributable to prediction error of the soil spectroscopy model (t CO_2e)^2

$\overline{SOC}_{wp,h,f}$ = Mean estimate of SOC stocks across all points in the project scenario at t_{final} in stratum h in the lth simulation (t CO_2e/ha)

$SOC_{wp,h,ip,f,l}$ = Estimated SOC stocks on an area basis at point *ip* in the project scenario at t_{final} in stratum h in the lth simulation (t CO_2e/ha)

$SOC_{wp,h,ip,s,l}$ = Estimated SOC stocks on an area basis at point *ip* in the project scenario at t_{start} in stratum h in the lth simulation (t CO_2e/ha)

$SOC_{wp,f,l}$ = Estimate of total SOC stocks on an area basis in the project scenario across the entire project at t_{final} in the lth simulation (t CO_2e)

$\overline{SOC}_{wp,f}$ = Mean estimate of total SOC stocks in the project scenario across the entire project at t_{final} averaged across all L simulations (t CO_2e)

Where a project proponent elects not to use the MC simulation approach and instead estimate model error using a simple frequentist approach, then $s^2_{SOC,wp,hf,model}$ in Equation (72) is replaced with an estimate of model prediction error that is the same across all strata and both scenarios, $s^2_{SOC,model}$. This estimate is determined by comparing modeled estimates of SOC to values determined through laboratory analysis (Appendix 4).

$$s^2_{SOC,model} = \frac{A^2}{tvd - 1} \sum_{pvd=1}^{tvd} \left(error_{pvd} - mean\ error\right)^2 \tag{73}$$

$$error_{pvd} = SOC_{model,pvd} - SOC_{observed,pvd}$$

$$mean\ error = \frac{1}{tvd} \sum_{pvd=1}^{tvd} error_{pvd}$$

Where:

$s^2_{SOC,model}$ = Variance of the estimate of SOC stocks attributable to prediction error of the soil spectroscopy model (t CO_2e)^2

$error_{pvd}$ = Difference between the predicted estimate of SOC on an area basis and observed SOC at point *pvd* in the randomly selected statistical validation dataset (t CO_2e/ha)

$mean\ error$ = Mean of all estimates of $error_{pvd}$ across all *tvd* points in the statistical validation dataset (t CO_2e/ha)

$SOC_{model,pvd}$ = Predicted estimate of SOC on an area basis at point *pvd* in the randomly selected statistical validation dataset (t CO_2e/ha)

$SOC_{observed,pvd}$ = Observed SOC on an area basis at point *pvd* in the randomly selected statistical validation dataset, determined through conventional lab analysis and field sampling (t CO_2e/ha)

pvd = 1, …, tvd sample points within the statistical validation dataset

Furthermore, $s^2_{SOC,wp,h,f,sample}$ should be determined using the same equation as is used to determine $s^2_{SOC,wp,h,f}$ in Equation (71), but individual point values are instead the value for that point as predicted by the soil spectroscopy model.

8.6.2.2 Extensions to Other Sampling Designs

In this simplified example, it is assumed that a single control plot or area is sufficient to represent the baseline scenario for each stratum and that the same soil sampling points can be revisited at both time points. In practice, such assumptions may not hold true in many projects developed under this methodology. Nonetheless, the overall process for estimating the total variance of the estimate of change should be similar to the example provided above. Equations used to estimate the individual component terms are likely to differ. As with Quantification Approach 1, an additional example is provided in Appendix 6 based on a multi-stage sampling design where stratified random sampling is employed at the final stage when determining location of sampling points.

8.6.3 Quantification Approach 3

In Quantification Approach 3, reductions and removals are estimated using emission factors (EF) determined to be most relevant for the project area (see Section 8.3 for additional details on EF selection). Whenever available, disaggregated values which are best applicable to the project area, project conditions, and project activity must be used. While these EFs are likely to include some prediction error, availability of source data for estimating that error may be inconsistent.

Project proponents must use the available EF that results in the most conservative reduction and removal estimates when applied across both the baseline and project scenarios. For example, IPCC (2019) provides 0.016 as the default emission factor to estimate N_2O emissions from managed soils resulting from synthetic fertilizer inputs in wet climates with an uncertainty range of 0.013–0.019. To yield the most conservative result, quantification of baseline and project scenario emissions must apply 0.013 (the lowest value in the uncertainty range) when project emission sources decrease relative to the baseline. When emission sources increase in the project scenario relative to the baseline, projects must apply 0.019 (the highest value in the uncertainty range).

It is expected that management data is collected across all quantification units in the project area according to the hierarchy outlined in Box 1, and as such sampling error does not factor into uncertainty deductions. However, where management data cannot be collected across the entire project area, sampling error must be accounted. In this case, the procedures for estimating sampling error in Quantification Approach 1 must be followed (see Section 8.6.1). The uncertainty estimators must be based on the sampling design used. Project proponents must provide a description of the sampling design and a justification as to why management data are not collected across all quantification units.

8.6.4 Uncertainty Deductions

Uncertainty deductions are estimated and applied separately for each reduction and removal source within the project boundary. This deduction is estimated using a probability of exceedance method as follows (see the most recent version of the *VCS Methodology Requirements* Section 2.4):

$$UNC_{\overline{\Delta}\cdot,t} = \left(\frac{\sqrt{s^2_{\overline{\Delta}\cdot,t}}}{\overline{\Delta\cdot}_t} \times 100 \right) \times t_{0.667} \tag{74}$$

Where:

$UNC_{\overline{\Delta}\cdot,t}$ = Uncertainty deduction for each GHG or C pool • to be applied in verification period *t* (%)

$\overline{\Delta\cdot}_t$ = Mean ERR for each GHG or C pool • across the entire project area in year *t* (t CO_2e/ha)

$s^2_{\overline{\Delta}\cdot,t}$ = Variance of the mean ERR estimate from each GHG or C pool • at time *t*. See Figure 5~~Figure 4~~ to determine how this is estimated based on the methods employed in the project (t CO2e/ha)^2

$t_{0.667}$ = *t*-value for a one-sided student's *t*-distribution at 0.667 (66.7%) confidence interval with degrees of freedom appropriate to the sampling design used. Equal to approximately 0.4307 at large sample sizes (dimensionless)

This uncertainty deduction is based on a defined threshold in the estimated probability density function of the reduction or removal for a given source. This enables a judgement of the extent to which the achieved reduction or removal by the project may be expected to be accurate. By this procedure, one estimates what percentage of the estimates of $\overline{\Delta\cdot}_t$ would have a 66.6% probability of exceeding the true value of $\overline{\Delta\cdot}_t$. That percentage is then used as the uncertainty deduction. Figure 5~~Figure 4~~ demonstrates this concept.

Figure 5~~54~~: Probability of exceedance. The value for $\overline{\Delta\cdot}_t$ used in calculation of VCUs issued is determined by applying an uncertainty deduction based on the 33.3rd percentile of the estimated probability distribution of $\overline{\Delta\cdot}_t$

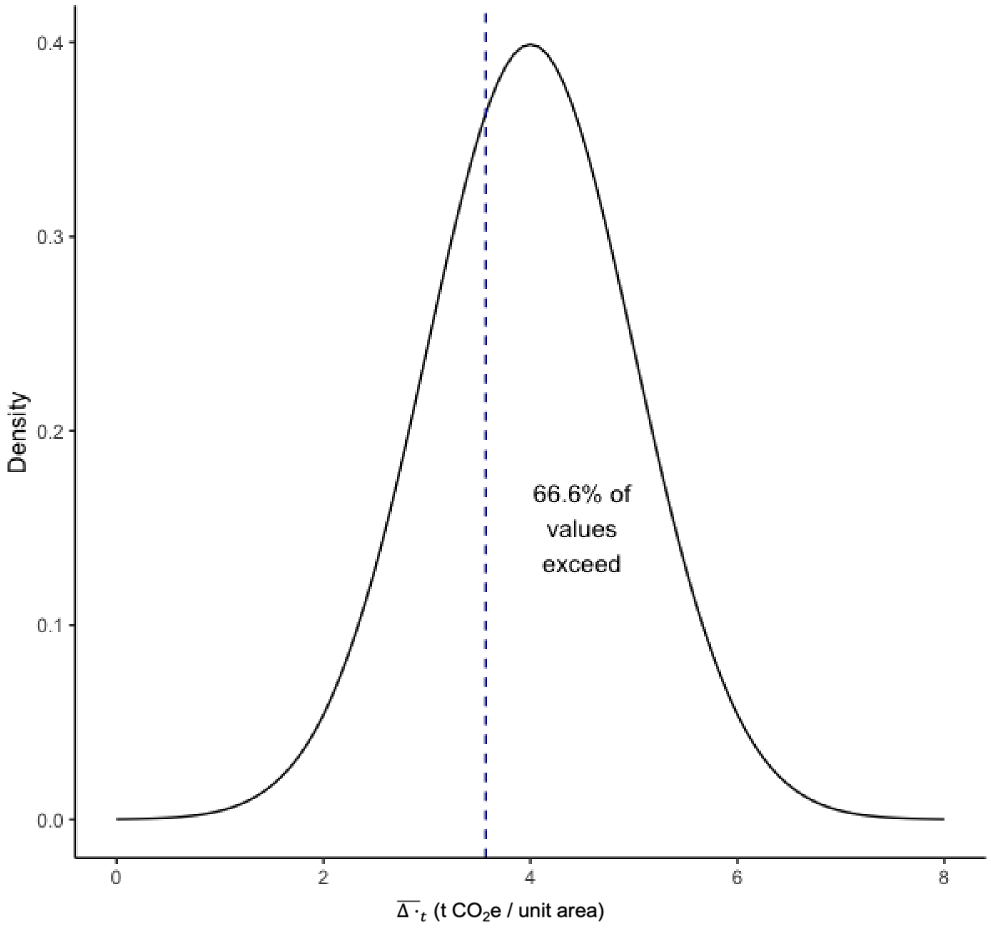
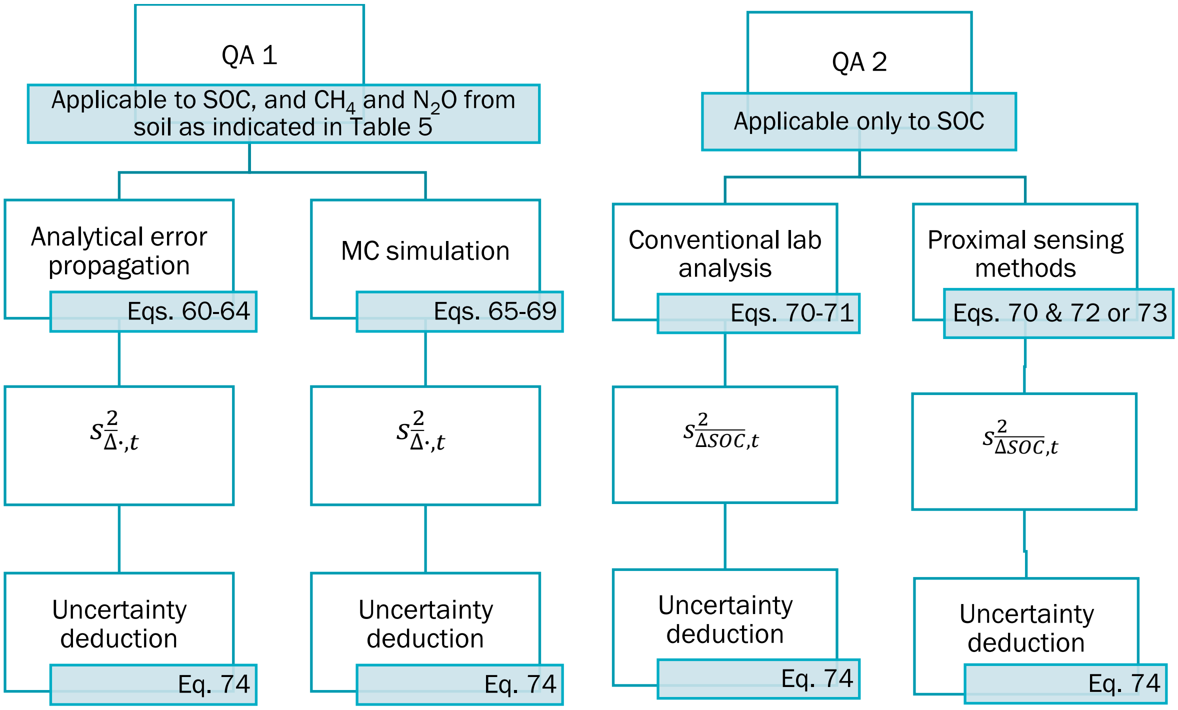

Density
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
66.6% of values exceed
$\overline{\Delta\cdot}_t$ (t CO_2e / unit area)

Figure 6~~65~~: Equation map for calculating uncertainty deduction under Quantification Approaches 1 (for SOC, CH_4, and N_2O) and 2 (for SOC)[58]



8.7 Calculation of Verified Carbon Units

To calculate the number of Verified Carbon Units (VCUs) that may be issued, the project proponent must consider the number of buffer credits that must be deposited in the AFOLU pooled buffer account. The number of buffer credits that must be deposited is calculated by multiplying the non-permanence risk rating by the net change in carbon stocks (see most recent version of the *VCS Standard*[59]). The buffer credits are quantified as:

$$
\begin{aligned}
Bu_{ER,t} = \; & I(\Delta CO2_{wp}) \times (\,\mathrm{MIN}(0, \Delta CO2_{wp,t}) - \mathrm{MIN}(0, \Delta CO2_{bsl,t})) \times NPR\% + (1 \\
& - I(\Delta CO2_{wp})) \times \;(\,\mathrm{MIN}(0, \Delta CO2_{wp,t}) - \mathrm{MIN}(0, \Delta CO2_{bsl,t}) \\
& + \;\mathrm{MAX}(0, \Delta CO2_{wp,t}) - \;\mathrm{MAX}(0, \Delta CO2_{bsl,t})) \times NPR\%
\end{aligned}
\tag{75}
$$

Where:

$I(\Delta CO2_{wp}) = 1$ if $\sum_1^t \; \Delta CO2_{wp,t} > 0$ and;

$I(\Delta CO2_{wp}) = 0$ if $\sum_1^t \; \Delta CO2_{wp,t} \leq 0$

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[58] Note that where a sample design other than the default stratified random sampling approach (see Section 8.2.1) is proposed via a methodology deviation, these equations should not be used but the general workflow is the same.

[59] For example, this is included in Section 3.2.10 of the *VCS Standard, v4.7*.

$Bu_{ER,t}$ = Buffer credits to be deducted from reductions in year *t* (t CO2e)

$$Bu_{CR,t} = I\left(\Delta CO2_{wp}\right) \times (\, MAX(0, \Delta CO2_{wp,t}) - MAX(0, \Delta CO2_{bsl,t})) \times NPR\% \tag{76}$$

Where:

$I\left(\Delta CO2_{wp}\right) = 1$ if $\sum_1^t \Delta CO2_{wp,t} > 0$ and;

$I\left(\Delta CO2_{wp}\right) = 0$ if $\sum_1^t \Delta CO2_{wp,t} \leq 0$

$Bu_{CR,t}$ = Buffer credits to be deducted from removals in year *t* (t CO2e)
$\Delta CO2_{wp,t}$ = Total carbon stock change in the project scenario in year *t* (t CO2e)
$\Delta CO2_{bsl,i,t}$ = Total carbon stock change in the baseline scenario in year *t* (t CO2e)
$NPR\%$ = Overall project non-permanence risk rating converted to a percentage

The number of VCUs resulting from project activities leading to reductions that may be issued in year *t* is calculated as:

$$VCU_{ER,t} = ER_{NET,t} - Bu_{ER,t} \tag{77}$$

Where:

$VCU_{ER,t}$ = Number of Verified Carbon Units resulting from project activities leading to reductions in year *t*
$ER_{NET,t}$ = Estimated net reductions in year *t* (t CO2e)

The number of VCUs resulting from project activities leading to removals that may be issued in year *t* is calculated as:

$$VCU_{CR,t} = CR_{NET,t} - Bu_{CR,t} \tag{78}$$

Where:

$VC_{CR,t}$ = Number of Verified Carbon Units resulting from project activities leading to removals in year *t*
$CR_{NET,t}$ = Estimated net removals in year *t* (t CO2e)

The number of VCUs that may be issued in year *t* is calculated as:

$$VCU_t = VCU_{ER,t} + VCU_{CR,t} \tag{79}$$

Where:

VCU_t = Number of VCUs in year *t* (t CO2e)

9 MONITORING

Where discretion exists in the selection of a value for a parameter, the principle of conservativeness must be applied (see the most recent version of the *VCS Standard*).

9.1 Data and Parameters Available at Validation[60]

Data/Parameter	$FFC_{bsl,j,i,t}$
Data unit	Liters
Description	Consumption of fossil fuel type *j* (gasoline or diesel) for quantification unit *i* in year *t* in the baseline scenario
Equations	(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	Fossil fuel consumption may be monitored or the amount of fossil fuel combusted may be estimated using fuel efficiency (e.g., l/100 km, l/t-km, l/hour) of the vehicle and the appropriate unit of use for the selected fuel efficiency (e.g., km driven where efficiency is given in l/100 km).
Purpose of data	Calculation of baseline emissions
Comments	Peer-reviewed published data may be used to determine fuel efficiency. For example, fuel efficiency factors may be obtained from Chapter 3, Volume 2 of IPCC (2019).

Data/Parameter	$M_{Limestone,bsl,i,t}$ and $M_{Dolomite,bsl,i,t}$
Data unit	tonnes/year
Description	Amount of calcitic limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) applied to quantification unit *i* in year *t* in the baseline scenario
Equations	(9)
Source of data	See Box 1

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[60] Parameters are listed in order of appearance in the respective equations.

Value applied	Amount of calcitic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) applied to quantification unit *i* in year *t*
Justification of choice of data or description of measurement methods and procedures applied	All limestone and dolomite applied to soils should be included, even the proportion applied in mixture with fertilizers. Use of oxides (e.g., CaO) and hydroxides of lime for soil liming is not required to be included in the calculations to estimate CO_2 emissions from liming. Because these materials do not contain inorganic carbon, CO_2 is not released following soil application; it is only produced during material manufacture.
Purpose of data	Calculation of baseline emissions
Comments	None

Data/Parameter	$Pop_{bsl,l,i,t,P}$
Data unit	Head
Description	Population of grazing livestock of type *l* in the baseline scenario in quantification unit *i* for productivity system *P* in year *t*
Equations	(11), (12), (28)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	Record of number of grazing livestock by type
Purpose of data	Calculation of baseline emissions
Comments	None

Data/Parameter	GWP_{CH4}
Data unit	t CO_2e/t CH_4
Description	Global warming potential for CH_4
Equations	(10)–(12), (14)
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." Global warming potential values must be applied as described in the most recent version of the *VCS Standard* and derived from IPCC Assessment Reports.
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	$W_{bsl,l,i,t,P}$
Data unit	kg animal mass/head
Description	Average weight in the baseline scenario of livestock type *l* for quantification unit *i* in productivity system *P* in year *t*
Equations	(13)
Source of data	See Box 1. Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 values from Table 10A.5, Chapter 10, Volume 4 in IPCC (2019) may be selected.
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 project emissions
Comments	None

Data/Parameter	$MB_{bsl,c,i,t}$
Data unit	kg
Description	Mass of agricultural residues of type *c* burned in the baseline scenario for quantification unit *i* in year *t*
Equations	(14), (32)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of	Peer-reviewed published data may be used to estimate the aboveground biomass prior to burning.

measurement methods and procedures applied	
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 remaining residues are burned. It is assumed that 100% of aboveground biomass is burned in the baseline scenario.

Data/Parameter	GWP_{N2O}
Data unit	t CO_2e/t N_2O
Description	Global warming potential for N_2O
Equations	(15), (18), (22)–(24), (27), (30)–(32)
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." Global warming potential values must be applied as described in the most recent version of the *VCS Standard* and derived from IPCC Assessment Reports.
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	$M_{bsl,SF,i,t}$
Data unit	t fertilizer
Description	Mass of N-containing synthetic fertilizer type *SF* applied in quantification unit *i* in year *t* in the baseline scenario
Equations	(19)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of	See Box 1

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

Data/Parameter	$M_{bsl,OF,i,t}$
Data unit	t fertilizer
Description	Mass of N-containing organic fertilizer type *OF* applied in the baseline scenario for quantification unit *i* in year *t*
Equations	(20)
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	$MB_{g,bsl,i,t}$
Data unit	t d.m.
Description	Annual aboveground and belowground dry matter of N-fixing species *g* returned to soils in the baseline scenario for quantification unit *i* in year *t*
Equations	(25)
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	$MS_{bsl,l,i,t}$
Data unit	Fraction of N deposited
Description	Fraction of nitrogen excretion by livestock type *l* that is deposited in quantification unit *i* in year *t* in the baseline scenario
Equations	(28)
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures 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 *t* for each livestock type *l*. 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 livestock deposit 100% of their excreted N on the project area for the entirety of year *t*.
Purpose of data	Calculation of baseline and project emissions
Comments	None

Data/Parameter	*A*
Data unit	Hectare (ha)
Description	Project area
Equations	(62), (63), (64), (66), (68)–(73)
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 measurement methods and procedures applied	Delineation of the project area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), and other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, landmarks, or other intersection points.
Purpose of data	Calculation of baseline and project emissions

Comments	Other units used to determine project area (e.g., acres) must be converted to hectares.

9.2 Data and Parameters Monitored

Data/Parameter	*MDD*
Data unit	t CO_2e/ha
Description	Minimum detectable difference in SOC stocks between two points in time
Equations	(1), (2)
Source of data	Estimation of the smallest difference in SOC stocks between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied	See Section 8.2.1
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 8.2.1 and further guidance in FAO (2019)
Purpose of data	Development of sampling strategy for baseline setting and measurements for monitoring
Calculation method	See Section 8.2.1
Comments	Calculating the number of samples required to detect a minimum difference is optional.

Data/Parameter	S
Data unit	Dimensionless
Description	Standard deviation of the difference in SOC stocks between t_0 and t_1
Equations	(1), (2)
Source of data	Estimation of the smallest difference in SOC stocks between two monitoring events that may be detected as statistically significant

Description of measurement methods and procedures to be applied	See Section 8.2.1
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 8.2.1 and further guidance in FAO (2019)
Purpose of data	Development of sampling strategy for baseline setting and measurements for monitoring
Calculation method	See Section 8.2.1
Comments	Calculation of the number of samples required to detect a minimum difference is optional.

Data/Parameter	n
Data unit	Dimensionless
Description	Number of samples required to detect a minimum difference
Equations	(1), (2)
Source of data	Estimation of the smallest difference in SOC stocks between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied	See Section 8.2.1
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 8.2.1 and further guidance in FAO (2019)
Purpose of data	Development of sampling strategy for baseline setting and measurements for monitoring
Calculation method	See Section 8.2.1
Comments	Calculating the number of samples required to detect a minimum difference is optional.

Data/Parameter	$n - 1$
Data unit	Dimensionless

Description	Degrees of freedom for the relevant t-distribution
Equations	(1), (2)
Source of data	Estimation of the smallest difference in SOC stocks between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied	See Section 8.2.1
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 8.2.1 and further guidance in FAO (2019)
Purpose of data	Development of sampling strategy for baseline setting and measurements for monitoring
Calculation method	See Section 8.2.1
Comments	Calculating the number of samples required to detect a minimum difference is optional.

Data/Parameter	$t_{x,u}$
Data unit	Dimensionless
Description	Values of the t-distribution given a certain power level $(1 - b)$ and a significance level
Equations	(1), (2)
Source of data	Estimation of the smallest difference in SOC stocks between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied	See Section 8.2.1
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 8.2.1 and further guidance in FAO (2019)
Purpose of data	Development of sampling strategy for baseline setting and measurements for monitoring
Calculation method	See Section 8.2.1

Comments	Calculating the number of samples required to detect a minimum difference is optional.

Data/Parameter	$M_{n,dl,SOC}$
Data unit	kg/ha
Description	SOC mass in soil sample *n* in depth layer *dl*
Equations	(3)
Source of data	Measured after soil sampling in the project area
Description of measurement methods and procedures to be applied	See Section 8.2.1
Frequency of monitoring/recording	Measurement of SOC stocks must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 8.2.1 Soil mass must not include particles greater than 2 mm in diameter (i.e., gravel/stones) nor plant material. Beem-Miller et al. (2016) provide a useful approach to ensuring high-quality sampling in rocky agricultural soils.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Wendt and Hauser (2013) and von Haden et al. (2020) provide spreadsheets and R scripts to standardize and facilitate calculations of SOC stock calculations with multiple soil depth increments.
Comments	None

Data/Parameter	$M_{n,dl,sample}$
Data unit	g
Description	Soil mass of sample *n* in depth layer *dl*
Equations	(3)
Source of data	Measured after soil sampling in the project area
Description of measurement methods and procedures to be applied	See Section 8.2.1

Frequency of monitoring/recording	Measurement of SOC stocks must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 8.2.1 Soil mass must not include particles greater than 2 mm in diameter (i.e., gravel/stones) nor plant material. Beem-Miller et al. (2016) provide a useful approach to ensuring high-quality sampling in rocky agricultural soils.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Mass of gravel/stones and plant material must be subtracted from the sample mass to obtain soil mass.
Comments	None

Data/Parameter	*D*
Data unit	mm
Description	Inside diameter of probe or auger
Equations	(3)
Source of data	Measured as part of project monitoring
Description of measurement methods and procedures to be applied	Information from product specifications of probe or auger
Frequency of monitoring/recording	Measurement of SOC stocks must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 8.2.1
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	*N*
Data unit	Unitless

Description	Number of cores sampled
Equations	(3)
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 8.2.1).
Frequency of monitoring/recording	Measurement of SOC stocks must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 8.2.1
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$OC_{n,dl}$
Data unit	g/kg
Description	Organic carbon content in sample n from depth layer dl
Equations	(3), (4)
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 4.
Frequency of monitoring/recording	Measurements of SOC stocks must be conducted at least every five years, or, when following quantification approach 2, prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See Section 8.2.1
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable

Comments	None

Data/Parameter	BD_{corr}
Data unit	g/cm^3
Description	Corrected bulk density of the fine soil fraction (after subtracting the mass proportion of the coarse fragments)), for calibration of SOC models
Equations	(4)
Source of data	See *VMD0053* for bulk density data requirements for model calibration and statistical validation
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Measurements of SOC stocks must be conducted at least every five years.
QA/QC procedures to be applied	See Sections 8.2.1.3 and 8.2.1.5 for general sampling and measurement guidance relevant for bulk density data
Purpose of data	Modeling of baseline scenario, calculation of baseline and project emissions
Calculation method	Fine soil fraction mass minus mass proportion of the coarse fragments
Comments	Only required when following Quantification Approach 1 for SOC stock changes

Data/Parameter	d
Data unit	cm
Description	Soil depth
Equations	(4)
Source of data	See *VMD0053* for requirements on calibration datasets
Description of measurement methods and procedures to be applied	Soil depth for each depth increment to be captured as part of data collection following requirements in *VMD0053*
Frequency of monitoring/recording	Measurements of SOC stocks must be conducted at least every five years.

QA/QC procedures to be applied	See *VMD0053* for requirements on calibration datasets
Purpose of data	Modeling of baseline scenario, calculation of baseline and project emissions
Calculation method	Not applicable
Comments	Only required when following Quantification Approach 1 for SOC stock changes

Data/Parameter	$ƒ(SOC_{bsl,i,t})$
Data unit	t CO_2e/ha
Description	Modeled SOC stocks in the baseline scenario for quantification unit *i* at time *t*, calculated by modeling SOC stock changes over the course of the preceding year
Equations	(5)
Source of data	See *VMD0053*
Description of measurement methods and procedures to be applied	Modeled SOC stocks in the baseline scenario are determined according to the following equation: $SOC\_soil_{bsl,i,t} = ƒ_{SOC}\left(Val\ A_{bsl,i,t}, Val\ B_{bsl,i,t}, \ldots\right)$ Where: $SOC\_soil_{bsl,i,t}$ = Modeled SOC stocks in the baseline scenario for quantification unit *i* at time *t* (t CO_2e/ha) $ƒ_{SOC}$ = Model predicting carbon dioxide emissions from the SOC pool (t CO_2e/ha) $Val\ A_{bsl,i,t}$ = Value of model input variable *A* in the project scenario for quantification unit *i* at time *t* (units unspecified) $Val\ B_{bsl,i,t}$ = Value of model input variable *B* in the project scenario for quantification unit *i* at time *t* (units unspecified) quantification unitquantification unitquantification unitSee 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	Measurements must be conducted at least every five years. Modeling as means of monitoring must be conducted prior to each verification event where verification occurs more frequently than once every five years.

QA/QC procedures to be applied	See *VMD0053*
Purpose of data	Calculation of baseline emissions following Quantification Approach 1
Calculation method	Not applicable
Comments	The SOC stocks at time t = 0 are calculated based on directly measured SOC content and bulk density at t = 0 or (back-) modeled to t = 0 from measurements within ±5 years of t = 0. See Section 8.2.1 for requirements for SOC content and bulk density measurements.

Data/Parameter	i
Data unit	Dimensionless
Description	Quantification unit. Defined area that is selected for measurement and monitoring, such as a field or stratum. See also definition in Section 2.
Equations	(5)–(32), (46)–(59)
Source of data	Determined in project area
Description of measurement methods and procedures to be applied	The quantification units are determined prior to verification.
Frequency of monitoring/recording	The quantification units must be reported at every verification, including adaptations from the previous verification periods.
QA/QC procedures to be applied	See definition in Section 2 for considerations on defining quantification units
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	A_i
Data unit	Hectare
Description	Area of quantification unit i
Equations	(6), (8), (11), (12), (14), (18), (21), (24), (27), (29), (32), (46)–(59)

Source of data	Measurement of each quantification unit within the project area
Description of measurement methods and procedures to be applied	The quantification unit area is measured prior to verification.
Frequency of monitoring/recording	The quantification units must be reported at every verification, including adaptations from the previous verification periods.
QA/QC procedures to be applied	Delineation of the quantification unit area may be determined using a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), and other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, landmarks, or other intersection points.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	Other units used to determine area (e.g., acres) must be converted to hectares.

Data/Parameter	j
Data unit	Dimensionless
Description	Type of fossil fuel combusted
Equations	(6), (7)
Source of data	Determined in quantification 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 where verification occurs more frequently.
QA/QC procedures to be applied	See Box 1
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{CO2,j}$
Data unit	t CO_2e/liter
Description	Emission factor for fossil fuel *j* (gasoline, diesel or other) combusted
Equations	(7)
Source of data	See Section 8.3 under Quantification Approach 3. For gasoline or diesel, EFs listed in Table 3.3.1 Chapter 3 Volume 2 in IPCC (2019) may be applied.
Description of measurement methods and procedures to be applied	For gasoline EF_{CO2} = 0.002810 t CO_2e per liter. For diesel EF_{CO2} = 0.002886 t CO_2e per liter
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data"
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	Assumes four-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	$FFC_{wp,j,i,t}$
Data unit	Liters
Description	Consumption of fossil fuel type *j* for quantification unit *i* in year *t* in the project scenario
Equations	(7)
Source of data	See Box 1
Description of measurement methods and procedures to be applied	Fossil fuel consumption may be monitored or the amount of fossil fuel combusted may be estimated using fuel efficiency (e.g., l/100 km, l/t-km, l/hour) of the vehicle type and the appropriate unit of use for the selected fuel efficiency (e.g., km driven where 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 where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Fuel efficiency factors may be obtained from Chapter 3, Volume 2 of 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	$EF_{Limestone}$ and $EF_{Dolomite}$
Data unit	t C/(t limestone or dolomite)
Description	Emission factor for the application of calcitic limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) (i.e., liming)
Equations	(9)
Source of data	Section 11.3, Chapter 11, Volume 4 in IPCC (2019)
Description of measurement methods and procedures to be applied	IPCC (2019) values: • For calcitic limestone $EF_{Limestone}$ = 0.12 t C/t limestone • For dolomite, $EF_{Dolomite}$ = 0.13 t C/t dolomite
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	See “Source of Data” and Section 8.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$f(CH4\_soil_{bsl,i,t})$
Data unit	t CH_4/ha

Description	Modeled methane emissions from soil in the baseline scenario for quantification unit *i* at time *t*, calculated by modeling soil methane fluxes over the course of the preceding year
Equations	(10)
Source of data	Modeled in the project area
Description of measurement methods and procedures to be applied	Modeled methane emissions from soil in the baseline scenario are determined according to the following equation: $$f(CH4\_soil_{bsl,i,t}) = f_{CH4soil}(Var\ A_{bsl,i,t}, Var\ B_{bsl,i,t}, \ldots)$$ Where: $f(CH4\_soil_{bsl,i,t})$ = Modeled methane emissions from the SOC pool in the baseline scenario for quantification unit *i* at time *t* (t CH_4/ha) $f_{CH4soil}$ = Model predicting methane emissions from the soil pool $Val\ A_{bsl,i,t}$ = Value of model input variable *A* in the baseline scenario for quantification unit *i* at time *t* (units unspecified) $Val\ B_{bsl,i,t}$ = Value of model input variable B in the baseline scenario for quantification unit *i* at time *t* (units unspecified) quantification unitquantification unitquantification unitSee 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 where verification occurs more frequently.
QA/QC procedures to be applied	See *VMD0053*
Purpose of data	Calculation of baseline and project emissions in Quantification Approach 1
Calculation method	Methods are specific to the model used.
Comments	None

Data/Parameter	$EF_{ent,l,P}$
Data unit	kg CH_4/(head × year)
Description	Enteric fermentation emission factor for livestock type *l* and productivity system *P*
Equations	(11)

Source of data	See Section 8.3 under Quantification Approach 3. 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 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.
Description of measurement methods and procedures to be applied	When using emission factors from Tables 10.10 and 10.11 (Chapter 10, Volume 4 in IPCC, 2019), the region most applicable to the project area must be selected. The tabulations in Annex 10A.1 (IPCC, 2019) provide details of the underlying animal characteristics such as weight, growth rate, and milk production used to develop the emission factors. Where project activities lead to agricultural systems transitioning from local low input productivity systems to higher productivity systems, more than one emission factor given for a specific animal category may be applied.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data" and Section 8.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$Pop_{wp,l,i,t,P}$
Data unit	Head
Description	Population of grazing livestock of type l in the project scenario in quantification unit i for productivity system P in year t
Equations	(11), (12), (28)
Source of data	See Box 1

Description of measurement methods and procedures to be applied	Record of number of grazing livestock by type. Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected quantification unit and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications).
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
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	*l*
Data unit	Dimensionless
Description	Type of livestock
Equations	(11)–(13), (23), (28), (31), (33)
Source of data	Determined in quantification 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 where verification occurs more frequently.
QA/QC procedures to be applied	See Box 1
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	P
Data unit	Unitless
Description	Productivity system
Equations	(11), (27), (28)
Source of data	Subsection “Definitions of High and Low Productivity Systems,” Section 10.2, Chapter 10, Volume 4 of IPCC (2019)
Description of measurement methods and procedures to be applied	When using emission factors from IPCC (2019), project proponents must differentiate between high- and low productivity systems for each livestock species to define value from Lookup Tables 10A.1 to 10A.9. Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. See also Box 1.
Frequency of monitoring/recording	To confirm that the productivity system remains the same, monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently. Any changes to the productivity system must be documented in each monitoring report.
QA/QC procedures to be applied	See “Source of data” and Section 8.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Following descriptions in IPCC (2019), basic population estimates may be applied (see “Source of data”).
Comments	None

Data/Parameter	$AWMS_{l,i,t,P,S}$
Data unit	Dimensionless
Description	Fraction of total annual volatile solids for each livestock type l that is managed in manure management system S in the project area, for productivity system P
Equations	(12), (28)
Source of data	See Section 8.3 under Quantification Approach 3. Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 average values for animal waste management systems (manure management systems) from Tables 10A.6 to 10A.9, Chapter 10, Volume 4 in IPCC (2019) may be selected.

Description of measurement methods and procedures to be applied	As emissions from manure management systems are highly temperature dependent, the climate zone associated with the entire project area where manure is managed must be considered.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data" and Section 8.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{CH4,md,l,P,S}$
Data unit	g CH_4/(kg volatile solids)
Description	Emission factor for methane emissions from manure deposition for livestock type *l* in productivity system *P* and manure management system *S*
Equations	(12)
Source of data	See Section 8.3 under Quantification Approach 3. Where no information source is available that is applicable to the project conditions, project proponents may derive emission factors based on project-specific manure characteristics and animal waste management system characteristics following the guidance under Tier 2 in Section 10.4.2, Chapter 10, Volume 4 of IPCC (2019). Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a values from Tables 10.14 and 10.15, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data" and Section 8.3 under Quantification Approach 3

Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	S
Data unit	Unitless
Description	Manure management system
Equations	(12), (22), (23), (27), (28)
Source of data	Table 10.18, Chapter 10, Volume 4 in IPCC (2019)
Description of measurement methods and procedures to be applied	See Section 8.3 under Quantification Approach 3. When using methane and nitrous oxide emission factors from IPCC (2019), project proponents must differentiate between manure management systems to define value from Lookup Tables 10.14 and 10.17. The referenced table of IPCC (2019) provides Tier 1a emission factors, which consider different aeration and mixing regimes as well as other factors such as water content, which influence CH_4 and N_2O emissions differently.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data" and Section 8.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$VS_{rate,l,P}$
Data unit	kg volatile solids/(1000 kg animal mass × day)
Description	Default volatile solids excretion rate for livestock type *l* and productivity system *P*
Equations	(13)
Source of data	See Section 8.3 under Quantification Approach 3. Where no information source is available that is applicable to the project conditions, project proponents may derive default factors using Equation 10.24 in Chapter

	10, Volume 4 in IPCC (2019). Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a values from Table 10.13a, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be 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 in IPCC (2019), the mean value may be selected.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	See "Source of data" and Section 8.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$W_{wp,l,i,t,P}$
Data unit	kg animal mass/head
Description	Average weight in the project scenario of livestock type *l* for quantification unit *i* in productivity system *P* in year *t*
Equations	(13)
Source of data	Estimated based on management records from project area
Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected quantification unit and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications).
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions

Calculation method	Not applicable
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	CF_c
Data unit	Proportion of pre-fire fuel biomass consumed
Description	Combustion factor for agricultural residue type *c*
Equations	(14), (32)
Source of data	Table 2.6, Chapter 2, Volume 4 in IPCC (2019)
Description of measurement methods and procedures to be applied	The combustion factor is selected based on the agricultural residue type burned.
Frequency of monitoring/recording	Source of data for combustion factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{c,CH4}$
Data unit	g CH_4/kg dry matter burnt
Description	Methane emission factor for the burning of agricultural residue type *c*
Equations	(14)
Source of data	Table 2.5, Chapter 2, Volume 4 in IPCC (2019)
Description of measurement methods and procedures to be applied	The emission factor is selected based on the agricultural residue type burned.

Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	c
Data unit	Dimensionless
Description	Type of agricultural residue
Equations	(14), (32)
Source of data	Determined in quantification 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 where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$MB_{wp,c,i,t}$
Data unit	kg
Description	Mass of agricultural residues of type *c* burned in the project for quantification unit *i* in year *t*

Equations	(14), (32)
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 (1 m × 1 m). The difference in the aboveground biomass is the aboveground biomass burned.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
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	$f(N2O\_soil_{bsl,i,t})$
Data unit	t N_2O/ha
Description	Modeled nitrous oxide emissions from soil in the baseline scenario for quantification unit *i* in year *t*, calculated by modeling soil fluxes of nitrogen forms over the course of the preceding year
Equations	(15)
Source of data	Modeled in the project area

Description of measurement methods and procedures to be applied	Modeled nitrous oxide emissions from soil in the baseline scenario are determined according to the following equation: $f(N2O\_soil_{bsl,i,t}) = f_{N2Osoil}(Var\ A_{bsl,i,t}, Var\ B_{bsl,i,t}, \dots)$ Where: $f(N2O\_soil_{bsl,i,t})$ = Modeled nitrous oxide emissions from soil in the baseline scenario for quantification unit *i* in year *t*, calculated by modeling soil fluxes of nitrogen forms over the course of the preceding year (t N_2O/ha) $f_{N2Osoil}$ = Model predicting nitrous oxide emissions from the soil pool $Val\ A_{bsl,i,t}$ = Value of model input variable *A* in the baseline scenario for quantification unit *i* at time *t* (units unspecified) $Val\ B_{bsl,i,t}$ = Value of model input variable *B* in the baseline scenario for quantification unit *i* at time *t* (units unspecified) quantification unitquantification unitquantification unitSee 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 where verification occurs more frequently.
QA/QC procedures to be applied	See *VMD0053*
Purpose of data	Calculation of baseline and project emissions in Quantification Approach 1
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{Ndirect}$
Data unit	t N_2O-N/t N applied
Description	Emission factor for direct nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments, and crop residues
Equations	(18), (24)
Source of data	See Section 8.3 under Quantification Approach 3. Where no information source is available that is applicable to the project conditions, project

	proponents may derive emission factors following the guidance in Chapter 11 Section 11.2.1.1 and Chapter 2 Section 2.2.4 in IPCC (2019). The emission factors will depend on, for example, 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. Where project proponents justify a lack of sufficient activity data and project-specific information sources, an appropriate disaggregated Tier 1 value from Table 11.1, Chapter 11, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	See “Source of data”
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	The emission factor is applicable to N additions from mineral fertilizers, organic amendments, and crop residues, and N mineralized from mineral soil as a result of SOC loss. Wet climates occur in temperate and boreal zones where the ratio of annual precipitation to potential evapotranspiration is greater than 1, and in tropical zones where annual precipitation is greater than 1000 mm. Dry climates occur in temperate and boreal zones where the ratio of annual precipitation to potential evapotranspiration is less than 1, and in tropical zones where annual precipitation is less than 1000 mm.

Data/Parameter	NC_{SF}
Data unit	t N/t fertilizer
Description	N content of synthetic fertilizer type SF
Equations	(19)
Source of data	See Box 1

Description of measurement methods and procedures to be applied	N content is determined following fertilizer manufacturer's specifications.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently. Parameter value must be updated when synthetic fertilizer product is changed or when new manufacturer's specifications are issued.
QA/QC procedures to be applied	See "Source of data" and Section 8.3 under Quantification Approach 3
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	SF
Data unit	Dimensionless
Description	Type of synthetic N fertilizer
Equations	(19)
Source of data	Determined in quantification 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 where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$M_{wp,SF,i,t}$

Data unit	t fertilizer
Description	Mass of N-containing synthetic fertilizer type *SF* applied in the project for quantification unit *i* in year *t*
Equations	(19)
Source of data	Management records from project area
Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected quantification unit and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications).
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
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	NC_{OF}
Data unit	t N/t fertilizer
Description	N content of organic fertilizer type *OF*
Equations	(20)
Source of data	Peer-reviewed published data may be used. For example, default manure N content may be selected from Edmonds et al. (2003) cited in US EPA (2011) or other regionally appropriate sources such as the European Environment Agency.
Description of measurement methods and procedures to be applied	See “Source of data”
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently. Parameter value must be updated when organic fertilizer product is changed or as

	new default values become available in peer-reviewed publications or databases.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	OF
Data unit	Dimensionless
Description	Type of organic N fertilizer
Equations	(20)
Source of data	Determined in quantification 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 where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$M_{wp,OF,i,t}$
Data unit	t fertilizer
Description	Mass of N-containing organic fertilizer type *OF* applied in the project for quantification unit *i* in year *t*
Equations	(20)

Source of data	Management records from project area
Description of measurement methods and procedures to be applied	Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected quantification unit and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications).
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
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	$Frac_{GASF}$
Data unit	kg N volatilized/kg N applied
Description	Fraction of all synthetic N added to soils that volatilizes as NH_3 and NO_x
Equations	(22)
Source of data	See Section 8.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.3, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions

Calculation method	Not applicable
Comments	None

Data/Parameter	$Frac_{GASM}$
Data unit	kg N volatilized/kg N applied
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	(22), (30)
Source of data	See Section 8.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.3, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$Frac_{LEACH}$
Data unit	kg N/kg N additions
Description	Fraction of N (synthetic or organic) 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
Equations	(23), (31)
Source of data	See Section 8.3 under Quantification Approach 3. When no information source is available that is applicable to the project

	conditions, project proponents may define value from Lookup Table 11.3, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	When using values from IPCC (2019), for wet climates and for dry climate regions where irrigation (other than drip irrigation) is used, a value of 0.24 is applied. For all other dry climate regions, a value of zero is applied.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	Wet climates occur in temperate and boreal zones where the ratio of annual precipitation to potential evapotranspiration is greater than 1, and in tropical zones where annual precipitation is greater than 1000 mm. Dry climates occur in temperate and boreal zones where the ratio of annual precipitation to potential evapotranspiration is less than 1, and in tropical zones where annual precipitation is less than 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	(23), (31)
Source of data	See Section 8.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.3, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.

QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$MB_{g,wp,i,t}$
Data unit	t d.m.
Description	Annual aboveground and belowground dry matter of N-fixing species *g* returned to soils for quantification unit *i* in year *t*
Equations	(25)
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	Information is monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the quantification unit. Any quantitative information (e.g., discrete or continuous numeric variables) on ALM practices must be supported by one or more forms of documented evidence pertaining to the selected quantification unit and relevant verification period (e.g., management logs, receipts or invoices, farm equipment specifications).
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
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	$N_{content,g}$
Data unit	t N/t d.m.

Description	Fraction of N in dry matter for N-fixing species *g*
Equations	(25)
Source of data	See Section 8.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.2, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	The fraction of N in dry matter is determined based on the N-fixing species type.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	*g*
Data unit	Dimensionless
Description	Type of N-fixing species
Equations	(25)
Source of data	Determined in quantification unit *i*
Description of measurement methods and procedures to be applied	See Box 1. N-fixing species 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 where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions

Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{N2O,md,l,S}$
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* and manure management system *S*
Equations	(27)
Source of data	See Section 8.3 under Quantification Approach 3. Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a values from Table 10.21, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	See "Source of data"
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$Nex_{l,P}$
Data unit	kg N deposited/(head × year)
Description	Annual average nitrogen excretion per head of livestock type *l* in productivity system *P*
Equations	(28)
Source of data	See Section 8.3 under Quantification Approach 3. Where no alternative information source is available that is applicable to the

	project conditions, project proponents may derive default factors using Equations 10.31 or 10.31a in Chapter 10, Volume 4 in IPCC (2019). Where project proponents justify a lack of sufficient activity data and project-specific information sources, Tier 1 and Tier 1a values from Table 10.19, Chapter 10, Volume 4 in IPCC (2019) may be selected.
Description of measurement methods and procedures to be applied	See “Source of data”
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
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	(22), (30)
Source of data	See Section 8.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 11.3, Chapter 11, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	See “Source of data”
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.

QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$EF_{c,N2O}$
Data unit	g N_2O/kg dry matter burned
Description	Nitrous oxide emission factor for the burning of agricultural residue type *c*
Equations	(32)
Source of data	See Section 8.3 under Quantification Approach 3. When no information source is available that is applicable to the project conditions, project proponents may define value from Lookup Table 2.5, Chapter 2, Volume 4 in IPCC (2019).
Description of measurement methods and procedures to be applied	The emission factor is selected based on the agricultural residue type.
Frequency of monitoring/recording	Source of data for emission factor must be monitored every five years and must be updated when more accurate data applicable to the project conditions become available following the guidance in Section 8.3 under Quantification Approach 3.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$M\_OA_{wp,l,t}$
Data unit	tonnes
Description	Mass of organic amendment applied as fertilizer (disaggregated by livestock type *l* for manure) on the project area in year *t*

Equations	(33)
Source of data	Management records from project area
Description of measurement methods and procedures to be applied	For manure application, data should be disaggregated for each livestock type *l*
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of leakage from application of new organic amendments from outside of the project area
Calculation method	Not applicable
Comments	None

Data/Parameter	$CC_{wp,oa,t}$
Data unit	t C/t organic amendment
Description	Carbon content of organic amendment (disaggregated by livestock type *l* for manure) applied as fertilizer on the project area in year *t*
Equations	(33)
Source of data	Carbon content provided by retailer of organic amendment may be used. Peer-reviewed published data may be used.
Description of measurement methods and procedures to be applied	Record of carbon content of organic amendment, where available. For manure application, data should be disaggregated for each livestock type *l*.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Guidance provided in IPCC (2003) Section 5.5 or IPCC (2000) Chapter 8 must be applied.
Purpose of data	Calculation of leakage from application of new organic amendments from outside of the project area
Calculation method	Not applicable
Comments	None

Data/Parameter	$\overline{SOC_{bsl,i,t}}$
Data unit	t CO_2e/ha
Description	Areal mean SOC stocks in the baseline scenario for quantification unit *i* in year *t*
Equations	(46)
Source of data	Modeled in the project area or measured in baseline control sites
Description of measurement methods and procedures to be applied	See parameter table for $f(SOC_{bsl,i,t})$ for modeled SOC stocks under Quantification Approach 1. Measured SOC under Quantification Approach 2 must be determined from samples collected from sample plots located within each baseline control site. See Section 8.2.1 for requirements for SOC content and bulk density measurements.
Frequency of monitoring/recording	Measurements must be conducted at least every five years. Modeling as means of monitoring must be conducted prior to each verification event where verification occurs more frequently than once every five years. SOC stocks in the baseline scenario for quantification unit *i* must be reported every five years or more frequently.
QA/QC procedures to be applied	See Section 8.2.1 and, for Quantification Approach 1, *VMD0053*
Purpose of data	Calculation of baseline emissions
Calculation method	Not applicable
Comments	SOC stocks at time *t* = 0 are calculated based on directly measured SOC content and ESM at *t* = 0 or (back-) modeled to *t* = 0 from measurements collected within ±5 years of *t* = 0. This initially measured SOC is the same in both the baseline and project scenarios at the outset of the project (i.e., $SOC_{wp,i,0} = SOC_{bsl,i,0}$) in Quantification Approach 1.

Data/Parameter	$\overline{SOC_{bsl,i,t-x}}$
Data unit	t CO_2e/ha

Description	Areal mean SOC stocks in the baseline scenario for quantification unit *i* in year *t* − *x*
Equations	(46)
Source of data	Modeled in the project area or measured in baseline control sites
Description of measurement methods and procedures to be applied	See parameter table for $\overline{SOC_{bsl,i,t}}$
Frequency of monitoring/recording	Measurements must be conducted at least every five years. Modeling as means of monitoring must be conducted prior to each verification event where verification occurs more frequently than once every five years. SOC stocks in the baseline scenario for quantification unit *i* must be reported every five years or more frequently.
QA/QC procedures to be applied	See Section 8.2.1 and, for Quantification Approach 1, *VMD0053*
Purpose of data	Calculation of baseline emissions
Calculation method	Not applicable
Comments	See parameter table for $\overline{SOC_{bsl,i,t}}$ See Section 8.2.1 for requirements for SOC content and bulk density measurements

Data/Parameter	$\overline{SOC_{wp,i,t}}$
Data unit	t CO_2e/ha
Description	Areal mean SOC stocks in the project scenario for quantification unit *i* in year *t*
Equations	(47)
Source of data	Modeled or measured in the project area
Description of measurement methods and procedures to be applied	Modeled SOC stocks in the project scenario are determined following the guidance in *VMD0053* and according to the following equation: $f(SOC_{wp,i,t}) = f_{SOC}\left(Var\ A_{wp,i,t}, Var\ B_{wp,i,t}, \ldots\right)$ Where: $f(SOC_{wp,i,t})$ = Modeled carbon dioxide emissions from SOC pool in the project for quantification unit *i* at time *t* (t CO_2e/ha) f_{SOC} = Model predicting carbon dioxide emissions from the SOC pool (t CO_2e/ha)

	$Val\ A_{wp,i,t}$ = Value of model input variable A in the project scenario for quantification unit i at time t (units unspecified) $Val\ B_{wp,i,t}$ = Value of model input variable B in the project scenario for quantification unit i at time t (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	Measurements must be conducted at least every five years. Modeling as means of monitoring must be conducted prior to each verification event where verification occurs more frequently than once every five years.
QA/QC procedures to be applied	See Section 8.2.1 and for Quantification Approach 1, *VMD0053*
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
Comments	Initially measured SOC stocks are the same in both the baseline and project scenarios at the outset of the project (i.e., $SOC_{wp,i,0} = SOC_{bsl,i,0}$) under Quantification Approach 1. SOC stocks at time $t = 0$ are calculated based on directly measured SOC content and ESM at $t = 0$ or (back-) modeled to $t = 0$ from measurements collected within ±5 years of $t = 0$. SOC stocks in the project scenario for quantification unit i must be reported every five years or more frequently under Quantification Approaches 1 and 2.

Data/Parameter	$\overline{SOC_{wp,i,t-x}}$
Data unit	t CO_2e/ha
Description	Areal mean SOC stocks in the project scenario for quantification unit i in year $t - x$
Equations	(47)
Source of data	Modeled or measured in the project area
Description of measurement methods and procedures to be applied	See parameter table for $\overline{SOC_{wp,i,t}}$
Frequency of monitoring/recording	Measurements must be conducted at least every five years. Modeling as means of monitoring must be conducted prior to each verification

	event where verification occurs more frequently than once every five years.
QA/QC procedures to be applied	See parameter table for $\overline{SOC_{wp,i,t}}$
Purpose of data	Calculation of project emissions
Calculation method	Not applicable
Comments	See parameter table for $\overline{SOC_{wp,i,t}}$

Data/Parameter	$\overline{\Delta C_{TREE,bsl,i,t}}$
Data unit	t CO_2e/ha
Description	Areal mean baseline carbon stock change in tree biomass for quantification unit *i* in year *t*
Equations	Section 8.2.2 and (48)
Source of data	Determined in project area
Description of measurement methods and procedures to be applied	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*
Frequency of monitoring/recording	Monitoring must be conducted at least every five years or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See “Description of measurement methods and procedures to be applied”
Purpose of data	Calculation of baseline emissions
Calculation method	See “Description of measurement methods and procedures to be applied”
Comments	None

Data/Parameter	$\overline{\Delta C_{SHRUB,bsl,i,t}}$
Data unit	t CO_2e/ha
Description	Areal mean baseline carbon stock change in shrub biomass for quantification unit *i* in year *t*

Equations	Section 8.2.2 and (50)
Source of data	Determined in project area
Description of measurement methods and procedures to be applied	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*
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See “Description of measurement methods and procedures to be applied”
Purpose of data	Calculation of baseline emissions
Calculation method	See “Description of measurement methods and procedures to be applied”
Comments	None

Data/Parameter	$\overline{\Delta C_{TREE,wp,i,t}}$
Data unit	t CO_2e/ha
Description	Areal mean project scenario carbon stock change in tree biomass for quantification unit *i* in year *t*
Equations	Section 8.2.2 and (49)
Source of data	Determined in project area
Description of measurement methods and procedures to be applied	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*. Where woody biomass is harvested, projects must calculate the long-term average GHG benefit following guidance in the most recent versions of the *VCS Methodology Requirements* and *VCS Standard*.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See “Description of measurement methods and procedures to be applied”
Purpose of data	Calculation of project emissions

Calculation method	See "Description of measurement methods and procedures to be applied"
Comments	None

Data/Parameter	$\overline{\Delta C_{SHRUB,wp,i,t}}$
Data unit	t CO_2e/ha
Description	Areal mean project scenario carbon stock change in shrub biomass for quantification unit *i* in year *t*
Equations	Section 8.2.2 and (51)
Source of data	Determined in project area
Description of measurement methods and procedures to be applied	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*. Where woody biomass is harvested, projects must calculate the long-term average GHG benefit following guidance in the most recent versions of the *VCS Methodology Requirements* and *VCS Standard*.
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	See "Description of measurement methods and procedures to be applied"
Purpose of data	Calculation of project emissions
Calculation method	See "Description of measurement methods and procedures to be applied"
Comments	None

Data/Parameter	•
Data unit	Dimensionless
Description	Gas or pool
Equations	(60)–(63)
Source of data	Determined in quantification unit *i*

Description of measurement methods and procedures to be applied	Not applicable
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Not applicable
Purpose of data	Calculation of baseline and project emissions
Calculation method	Not applicable
Comments	None

Data/Parameter	$\overline{\Delta \bullet_{h,t}}$ and $\overline{\Delta \bullet_{t}}$
Data unit	t CO_2e/ha
Description	Areal mean emission reductions in gas or pool • (in stratum *h*) in year *t*
Equations	(62), (63)
Source of data	Calculated from modeled or calculated values in the project area
Description of measurement methods and procedures to be applied	Not applicable
Frequency of monitoring/recording	Calculations and recording must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
QA/QC procedures to be applied	Comparison of project results with values from peer-reviewed literature under similar conditions. Raw data from laboratory analysis as well as calculation spreadsheets and/or computer code used for calculations must be provided as requested by the VVB.
Purpose of data	Calculation of emission reductions
Calculation method	Estimated using unbiased statistical approaches, such as from Cochran (1977). Application of this methodology may employ quantification units of unequal sizes, which would necessitate proper weighting of samples to derive means.
Comments	None

Data/Parameter	$BU_{ER,t}$
Data unit	t CO_2e
Description	Number of buffer credits to be deducted from reductions in year *t*
Equations	(75)
Source of data	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the most recent version of the VCS *AFOLU Non-Permanence Risk Tool*.
Description of measurement methods and procedures to be applied	Not applicable
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.
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 most recent version of the VCS *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 most recent version of the VCS *AFOLU Non-Permanence Risk Tool*.
Comments	None

Data/Parameter	$BU_{CR,t}$
Data unit	t CO_2e
Description	Number of buffer credits to be deducted from reductions in year *t*
Equations	(76)
Source of data	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the most recent version of the VCS *AFOLU Non-Permanence Risk Tool*.
Description of measurement methods and procedures to be applied	Not applicable
Frequency of monitoring/recording	Monitoring must be conducted at least every five years, or prior to each verification event where verification occurs more frequently.

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 most recent version of the VCS *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 most recent version of the VCS *AFOLU Non-Permanence Risk Tool*.
Comments	None

9.3 Description of the Monitoring Plan

The main objective of monitoring is to quantify stock change of SOC and emissions of CO_2, CH_4, and N_2O resulting from the project scenario during the verification period.

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:

- 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;
- Baseline control site management plans, where applicable, including location, boundaries, and demonstration of similarity criteria (see Table 7~~Table 7~~) for each baseline control site, with adequate detail to permit implementation of the annual schedule of activities for the linked quantification unit(s);
- Ten-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; 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 part of monitoring, including QA/QC data,

must be archived electronically and kept for at least two years after the end of the last project crediting period;

- Roles, responsibilities, and capacity of monitoring team and management; and
- Modeling plan, where Quantification Approach 1 is applied. The project modeling plan must describe the model(s) selected, describe the datasets used for model validation and calibration, including their sources, and specify the baseline schedule of ALM activities for each quantification unit (fixed ex ante).

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APPENDIX 1: NON-EXHAUSTIVE LIST OF POTENTIAL IMPROVED ALM PRACTICES THAT COULD CONSTITUTE THE PROJECT ACTIVITY

The following list presents the main categories of practices expected to enhance SOC stocks and/or reduce GHG emissions from soils under a range of cropping and livestock systems. However, the list is non-exhaustive; there are many other improved ALM practices with the potential to enhance SOC stocks and/or reduce GHG emissions as well as emerging practices (e.g., soil inoculants). Furthermore, terms used to denote the same or similar practices may differ regionally. Therefore, for the purposes of demonstrating eligibility (i.e., Applicability Condition 1) as well as additionality (i.e., Step 3 Common Practice) the project proponent must 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.

Improve fertilizer (organic or inorganic) application

- Optimization of fertilizer application (e.g., 4R Nutrient Stewardship – right source, rate, time, and placement)
- Organic fertilizer application (e.g., manure, compost)
- Enhanced efficiency nitrogen fertilizers (e.g., urease/nitrification inhibitors, controlled release fertilizers)

Improve water management/irrigation

- Alteration of irrigation (e.g., precision irrigation)
- Alternate wetting and drying (AWD) in rice systems
- Groundwater level management (e.g., adjust groundwater levels to reduce peat oxidation)

Reduce tillage/improve residue management

- Reduced tillage/conservation tillage
- Strip-till/mulch-till
- No-till
- Crop residue retention
- Avoidance of residue burning

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 during the same growing season
- Incorporation of fungal/microbial inoculants or other soil probiotics
- Agroforestry (integration of woody species into crops)

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 cover crops and agricultural residues post-harvest

- Silvipasture (integration of woody species into pastures)
- Integrated crop-livestock system (ICLS)

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[61] 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, ecosystems, and the ability to meet humanity's growing needs.

Degraded lands may be restored and rehabilitated through implementation of sustainable land management strategies, thereby reversing degradation and restoring productivity. In addition, such strategies may 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 lifetime. This exception allows for a one-time conversion from grassland to cropland or vice versa. However, project proponents must 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.

Step 1: Demonstration of Land Degradation

The project proponent must use the CDM *Tool for the identification of degraded or degrading lands for consideration in implementing CDM A/R project activities* to demonstrate that the land is degraded at the start of the project and will continue to degrade in the baseline scenario. The tool uses a two-stage process that involves:

- 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 10 years; or

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[61] Olsson, L., et al. (2019). Land degradation. In P. R. Shukla et al. (Eds.). *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (pp. 345–436). Available at: https://www.ipcc.ch/site/assets/uploads/sites/4/2019/11/07_Chapter-4.pdf

- In the absence of such study, identification through direct evidence based on indicators of degradation or through comparative studies. Exact procedures are outlined in the tool.

Step 2: Demonstration of Expected Improvements Resulting from Project Implementation

The project proponent must provide an analysis of how the proposed project activities will lead to restoration of project lands. Such analysis must be based on the degradation indicators identified in Step 1 and must at minimum include expected impacts on soil health, plant (i.e., crops, forage) productivity, biodiversity, local ecosystems, and livelihoods. Evidence types may include local expert analysis and relevant local, regional, or national studies. Where those are not available, international studies conducted under similar biophysical and climatic conditions and with comparable management practices may be used. Evidence may include quantification of recognized indicators of degradation by direct measurement, proximal or remote sensing, and/or modeling. 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).

APPENDIX 3: SELECTION AND JUSTIFICATION OF THE BASELINE SCENARIO

Current Global Agricultural Trends

The most recent OECD-FAO Agricultural Outlook provides a global baseline scenario for 2025–2034 based on specific assumptions about macroeconomic conditions, productivity trends, agriculture and trade policies, demographic developments, weather, and consumer preferences (OECD & FAO 2025).

Considering the data and policies in place as of December 2024, the baseline scenario for the decade 2025–2034 is characterized by rising demand for animal-based foods particularly in middle-income countries, production growth driven by productivity improvements especially in middle-income regions, continuous trade, and decline of real prices creating a significant challenge, especially for smallholder farmers, and increasing pressure to boost efficiency.

The outlook on productivity improvements and emission reductions relies strongly on the adoption of technological improvements. Direct GHG emissions could drop by 7% below current levels by 2034, but only if agricultural productivity increases by 15% and emission-reducing technologies are widely adopted. However, the expansion of animal herds and cropland contributes to a 6% increase in direct GHG emissions, despite lower emissions intensity per unit.

The current (2024) state of market conditions and trends, in terms of consumption, demand, and prices, for key commodities is compared to the 2015–2024 average as follows:

Key commodity	Market conditions, consumption, and price trends
Cereals	Growth in cereal production is expected to continue, driven mostly by yield increases. Harvested area expansion is modest (0.14% p.a.), much lower than in the prior decade. Demand from food and feed use remains the leading driver. Prices are slightly decreasing, suggesting a well-supplied market.
Oilseeds	Yields are improving, but some oilseed sectors see yield constraints (e.g., palm, rapeseed). Biofuel demand contributes to demand for vegetable oils, especially in middle-income countries. Prices for soybeans drop while production increases. In contrast, prices for palm oil, rapeseed, and sunflower seed grow as production remains below potential. Consumption trends show a moderate increase.
Sugar	Consumption is growing moderately while prices have fallen below the decadal average. Demand growth is concentrated in Africa and Asia, while consumption in high-income countries remains flat or declines.

Meat	Prices are increasing moderately due to strong demand. Meat-exporting countries are increasing production. Demand for poultry and beef remains high and growing. Per capita consumption is rising in all regions except Africa, most prominently in developed economies. Livestock production, meat, dairy, and egg output are projected to increase strongly (e.g., ~16% increase in output on protein basis). Livestock inventories (e.g., cattle, pigs, poultry) expand more modestly (~7%), which implies improved productivity. Feed demand is expected to grow by ~15% in protein equivalent.
Dairy	Global production and consumption are driven by a high demand in India and Pakistan, while demand is decreasing in China. Prices for butter reached a record high in 2024, impacting the overall price trend for dairy.
Fish and other products from aquaculture	Consumption is rising in most regions. Fish and aquaculture products are projected to grow (~12%) to help meet rising demand, especially in developing countries. Downward trend in prices since 2022.
Biofuels	Global consumption has grown steadily (on average 3.5% annually) over the last decade. Demand (consumption) currently at moderate levels (index around or just above 100). As a result of lower crude oil and feedstock prices, favourable tax policies, and strong economic incentives, overall prices show a strong declining trend.Biofuel demand is projected to grow ~0.9% p.a., driven by increasing transport fuel demand and policy support (notably in Brazil, India, and Indonesia). That growth will also place pressure on feedstock commodity markets (e.g. vegetable oils, biomass) and may influence price volatility.
Cotton	World cotton production increased in 2024 accompanied by declining prices. Consumption increased slightly due to higher cotton use in India, Bangladesh, Turkey, and Vietnam.

In summary, many agricultural commodities show consumption indices above their decadal average, reflecting strong recent demand – particularly in emerging economies. Supply (i.e., production and trade) has generally been able to respond to demand, moderating upward pressure on real prices. Potential for expansion of acreage or livestock numbers is limited. Thus, future growth is expected to arise more from productivity gains closing yield gaps and implementation of technological improvements.

The following uncertainty factors could significantly alter the projected trends:

1) Macroeconomic conditions (i.e., GDP growth, inflation, exchange rates, and interest rates) directly impacting agricultural demand (especially for higher-value foods), input costs (e.g. fuel, fertiliser, machinery), and trade competitiveness. Volatility or economic slowdown (e.g., in China, the EU, or the US) could suppress both global demand and investment in agriculture.
2) Weather variability and climate change, in particular extreme weather events (e.g., droughts, floods, heatwaves) disrupting production and trade flows. Shifting long-term climate trends, such as temperature rises, rainfall changes, and extreme events impact yields – especially in vulnerable regions – pest and disease outbreaks, water availability, and cropping patterns.

3) Energy and input prices, as agriculture is highly energy-intensive (e.g., for fertilizers, fuel, transport) causing a strong dependency on high or volatile energy prices potentially raising production costs, influencing GHG emissions from input use, and affecting biofuel competitiveness and feedstock demand (e.g., maize, sugar, vegetable oil).
4) Agricultural and trade policy could lead to changes in subsidies, tariffs, sanitary standards, or environmental regulations reshaping global flows. Trade tensions (e.g., US–China, EU–Brazil), export bans, or supply chain restrictions (as seen during COVID-19) may disrupt projections. Global efforts toward sustainability, nutrition, or climate targets (e.g., through WTO or UNFCCC processes) could shift priorities.
5) Technological progress and adoption are uncertain. The rate of innovation (e.g., digital farming, precision agriculture, biotechnology) and speed of adoption are very diverse across regions and commodities. Especially in low-income countries, barriers to technology uptake (e.g., cost, education, infrastructure) may limit expected productivity gains. Emission-reducing technologies are central to scenario outcomes, but their adoption is uneven and hard to predict.
6) Demographic and dietary shifts driven by population growth and urbanization patterns, which influence food demand and land use. Uncertainty factors encompass future dietary preferences (e.g., more plant-based diets, lab-grown meat, cultural value of nutrition and environmental impact of food choices), health policies or taxation (e.g. sugar taxes, meat taxes), and generational changes in food consumption.
7) Geopolitical instability and conflicts (e.g., Ukraine–Russia conflict) may disrupt production and exports of commodities and inputs, cause price spikes and market volatility, and trigger migration and changes in land use or labor availability.
8) Pandemics and global shocks, such as health crises, transport restrictions, or supply chain breakdowns could reshape production and access. Events like COVID-19 show how quickly global food systems can be disrupted.
9) Financial and investment flows is a strong uncertainty factor, especially for smallholders and developing countries. Disruptions in capital markets, or shifts in green finance and carbon credit systems, may accelerate or stall agricultural transitions.

The International Food Policy Research Institute (IFPRI) and the World Bank estimate that with the current business-as-usual scenario of governmental support for agriculture, GHG emissions would increase by 58%, and 56 million hectares would be converted to agricultural land by 2040 (Gautam et al. 2022). Although “green” government support promoting climate-friendly agriculture has increased in recent years, its share remains very low (~5%) both in volume and in the number of countries providing it. The bulk of support is linked to outputs, inputs, factors of production (e.g., land area), price regulation of products, or trade barriers, and focuses on supporting higher production regardless of environmental impact.

Alternative Scenarios to Improved ALM, Plausibility, and Uncertainties

Step 1a of VCS tool *VT0009 Combined Baseline and Additionality Assessment* requires identifying all realistic and credible alternative scenarios that deliver a comparable output or use a comparable input to a proposed project activity, as follows:

Scenario 1 (S1): Project is implemented but is not registered under a GHG/carbon credit program.

Scenario 2 (S2): No investment by the project proponent; output is provided by others or via business-as-usual practices by other actors.

Scenario 3 (S3): Continuation of current practices without additional investment or operational expenses

Scenario 4 (S4): Continuation of current practices with additional investments or requiring operational expenses

Scenario 5 (S5): Other plausible alternatives delivering the same output in the same region/sector or common practices already occurring

Scenario 6 (S6): The proposed project activity is undertaken without being registered as a project activity, and is implemented at a later point in time.

Considering hypothetical improved ALM projects (e.g., implementation of conservation agriculture (CA) involving the stacked practices of no-tillage, cover crops, and introducing legumes into a crop rotation in smallholder maize/wheat farms in Kenya or in large commercial soy/corn farms in Brazil), the following different scenarios and their plausibility are identified:

Scenario	Description	Plausibility and likelihood	Comparable input/output
S1	Adoption of CA independently from a carbon market project	Realistic if supported by external aid or NGOs	Limited scale, short-term implementation tied to external funding
S2	A cooperative, agribusiness, NGO, or government program independently implements CA in the same region, without the project proponent.	Plausible but limited scale	Limited scale, short-term implementation tied to external funding or government programs in a legislative period
S3	Business-as-usual: farmers continue conventional maize/wheat or soy/corn farming with full tillage and no cover crops.	Highly realistic as farmers are familiar with this agronomic practice, have the required access to equipment and inputs, and are supported by government subsidies and price regulation.	No GHG benefits

S4	Farmers adopt partial CA (e.g., no-tillage only).	Plausible if supported by government programs and extension services	Lower increase in SOC stocks and lower GHG emission reductions due to the missing synergistic effect of stacked practices. Adoption more likely to be reverted as adjustment challenges not addressed systemically (e.g., no-tillage alone may lead to higher weed occurrence without a suitable crop rotation).
S5	Farmers introduce synthetic inputs and new seed varieties but maintain conventional tillage without cover crops.	Plausible if supported by government programs and extension services	None or lower GHG benefit
S6	Adoption of CA in 5–10 years independently from a carbon market project	Realistic if supported by external aid or NGOs or if farmers observe good experiences from neighboring farms	Limited scale, short-term implementation tied to external funding or very slow adoption

As discussed above, multiple factors affect agricultural management and production. Changes in these factors will alter the likelihood of certain scenarios. Many of these are captured by the additionality assessment as required by the steps listed in Section 7. Furthermore, the baseline reassessment requirements per the most recent version of the *VCS Standard* and this methodology ensure that projects adjust their baseline to shifting policy, market, environmental, and technological developments. These additionality and baseline assessment requirements determine the eligibility of projects and project activities.

In the above example, if the adoption of CA became mandated by law in the project jurisdiction, Scenario 1 would become the most plausible. At the same time, the project activity would no longer be eligible in a carbon market context as it would not meet the regulatory surplus requirement (see Step 1 of Section 7). If recurring drought conditions stimulate short-term and large-scale adoption of CA, farmers may have greater motivation to implement CA without the incentive of carbon markets. The possible risk perception of adopting CA would be lower through the good experiences of neighboring farms. If adoption becomes common beyond the common practice adoption rate threshold of 20%, the project activity would no longer be eligible (see Step 3 of Section 7).

Continuation of Pre-project Historical Practices as the Most Plausible Baseline Scenario

As shown by the global outlook of agricultural production (OECD & FAO 2025), agricultural production is subject to multiple economic and policy pressures. While adoption of improved ALM and regenerative practices is increasing, regional uptake varies and key barriers to adoption prevail. Grand View Research, Inc. (2025) predicts that the regenerative agriculture market will have a compound annual growth rate of 18.7% by 2033. Growing concerns about soil degradation, climate change, and biodiversity loss are major motivators globally. North America is currently one of the largest markets and early adopters of regenerative practices, benefiting from strong corporate commitments, government incentives, soil health programs, and consumer demand. In Asia and the Pacific, adoption is growing fastest, driven by soil degradation concerns, large agricultural sectors, increasing government support, and rising consumer awareness in countries like India, China, and Australia. Adoption is still emerging in Africa, Latin America, and the Caribbean, often supported by ecosystem-based adaptation projects, NGO or multilateral funded programs, and corporate sourcing commitments. Adoption in Europe is supported under policy frameworks like the EU's Common Agricultural Policy (CAP), with increasing subsidies and incentives for soil-friendly farming and growing evidence for adoption of reduced tillage and cover cropping. However, adoption rates of conservation agriculture remain below 10% in most European countries.[62]

Farmers face multiple challenges when aiming to increase productivity to meet growing demand, with declining prices and the need to adapt to a changing climate. Farmers' decisions are influenced by a complex mix of economic, social, environmental, psychological, and institutional factors. Unlike standard business decision-making models that focus purely on profit maximization, farmer behavior is shaped by risk, identity, tradition, and long-term stewardship concerns. Finger et al. (2024) identified that European farmers show strong risk and loss aversion. They tend to overweight small probabilities and underweight large ones, decreasing uptake of new practices. In Zambia, risk aversion drives farmers toward safer, lower-yield options, sometimes trapping them in poverty despite better alternatives, as shown by Simutowe et al. (2024).

The farmer itself is the biggest determinant of what and how ALM practices are implemented through time, driving variability in historical and future management decisions. Thus, two farms that are similar on paper may be managed very differently due to the individual choices of each farm manager (Meijer et al. 2015; Pannell et al. 2006). Capturing that individual's influence on past decisions and assuming those choices and practices would occur in the future is the most appropriate representation of how each field would likely be managed in the absence of the carbon project.

Lack of knowledge, information, and awareness remain a key barrier to adoption of improved ALM (Lui et al. 2014; Piñeiro et al. 2020). Risk aversion and skepticism toward the economic benefit of new practices is another prevalent factor hindering the wider adoption of improved ALM practices. Many farmers experience lower yields or higher labor or management complexity in the first three to five years after initiating practice transition.

While the ecological benefits of improved ALM are well understood and a long-term economic benefit is widely recognized, the transition requires investments for different agricultural equipment, alternative inputs, and to cover potential short-term yield declines in the adjustment phase. Farm-specific

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[62] ECAF (n.d.) *Adoption of Conservation Agriculture in Europe*. https://ecaf.org/adoption-of-conservation-agriculture-in-europe/

knowledge and technical support is required to identify which practices work in which pedological and climatic contexts.

Given the persistent barriers and lack of long-term positive evidence from improved ALM in most farming contexts, the continuation of pre-project management practices is considered the most plausible and likely baseline scenario.

APPENDIX 4: GUIDANCE ON POTENTIAL EMERGING TECHNOLOGIES TO MEASURE SOC CONTENT

As indicated in Table 6~~Table 6~~ and Table 8~~Table 8~~ and the parameter tables related to modeled and measured SOC stocks (Section 9.2), project proponents may use emerging technologies to determine SOC content where 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.[63]

The applicability of a selected technology to measure SOC in a project must be demonstrated in at least three peer-reviewed scientific articles. Project proponents must 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, and land use. While project proponents 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 the VVB. Access must not be restricted through intellectual property rights.

Table 9

~~Table 9~~ 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.[64] 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 SOC stock that is of similar or better accuracy than lower density sampling measured with conventional analytical laboratory methods. Since many more proximal devices may be used in a project than would be used were all samples sent to a single laboratory, care must be taken to demonstrate device-to-device calibration and precision. Project

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[63] The listed technologies may be updated in future versions of VM0042. The use of remote sensing-based techniques for estimating SOC content is currently not allowed.

[64] A detailed comparison of cost-effectiveness of dry combustion and three MIR and Vis-NIR instruments was conducted by Li, S., Viscarra Rossel, R. A., & Webster, R. (2022). The cost-effectiveness of reflectance spectroscopy for estimating soil organic carbon. European Journal of Soil Science, 73(1), Article e13202. https://doi.org/10.1111/ejss.13202

proponents must provide details to the VVB on the criteria and considerations of the emerging SOC measurement technology as specified in the list below and in Table 9~~Table 9~~.

Projects must maintain adherence to these criteria over time to ensure that measurement and remeasurement are conducted under the same conditions and are thus comparable.

The following information must be included in the monitoring plan and reports where emerging technologies are applied:

1) Standard Operating Procedures for sample processing (including drying, sieving, rock and root removal, grinding) and analysis adapted to the proximal sensing technique to be applied
2) For in-field or laboratory measurements without sample processing, a detailed explanation of strategies to overcome potential measurement obstacles due to signal interference related to differences in soil moisture, soil aggregates, sunlight, shadow, coarse fragments, and other factors
3) Description of the technology and specific equipment and instrument to be applied, including spectral range covered by the instrument applied and the actual resolution of the measurements
4) Description of pretreatment or preprocessing methods to analyze raw spectral data
5) Description of the modeling approach applied for estimating SOC content based on proximal sensing data, including model type (e.g., partial least squares regression) and model features/parameters
6) Description of randomized data-splitting for model calibration/training and validation/testing. Commonly, 70% of the sample data is used for calibration/training and 30% for validation/testing. Other methods for data-splitting include k-fold cross-validation and bootstrapping.
7) Demonstration that calibration and statistical validation data are representative of the actual project area in terms of SOC content, clay type, clay content, Munsell soil color,[65] and application of organic amendments, where relevant.[66] For field-moist measurements, extensive verification of predictive performance across a wide range of moisture contents is required.
8) Goodness-of-fit metrics and descriptive statistics from the dataset, such as root mean square error (RMSE), R^2, ratio of performance to interquartile range (RPIQ), bias, and Lin's concordance correlation coefficient (CCC), or other suitable parameters
9) Description of the approach used to generate posterior predictive distributions (PPDs) or intervals used to propagate error from the spectroscopy model to calculations of the uncertainty deduction. PPDs may be based on Bayesian modeling methods that incorporate parameter uncertainty in the calibration/validation phase. Alternatively, PPDs may be based on estimates

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[65] The Munsell Color Value describes a soil's color based on the following properties: hue (basic color), chroma (color intensity), and value (lightness).

[66] SOC content from quantification units in which organic amendments are applied should be measured after thorough soil sample homogenization and grinding.

of model uncertainty derived by comparing results of dry combustion analysis for 10–15% of the samples from the project area to estimate SOC via spectroscopy at every verification event.

10) Demonstration that samples must be chosen in an unbiased manner such that they are representative of the project conditions and sampling design. For example, where a stratified random sampling approach is employed, selection of points should be area-weighted based on the area of each stratum relative to the total project area.

Table 9: Method-specific criteria to evaluate use of emerging technologies based on proximal sensing to measure SOC content

Method	Criteria and Considerations to Ensure Robustness and Reliability
Inelastic neutron scattering[67] (INS)	• Where carbonates are present (calcareous or limed soils), inorganic C must be separately accounted for. • Inorganic gamma scintillators (detectors based on 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 separation of the gamma ray spectrum due to INS reactions from thermal neutron capture and the delay activation reaction spectra.
Laser-induced breakdown spectroscopy (LIBS)	• Soil samples must be dried for at least 24 h at 40 °C or air-dried for at least 48 h at room temperature. • Where 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 evaporation and atomization in the plasma. • Before analysis, soil material must be pressed to form a pellet with a flat surface. • Configuration of the LIBS instrumental parameters must be optimized for each matrix. The laser pulse energy and the diameter of the laser beam (i.e., spot size) must be monitored simultaneously in the laser pulse fluence term (laser pulse energy per unit area, J/cm^2) as must be delay time and laser repetition rate. • Projects may rely on chemometric methods for signal analysis, spectral preprocessing, and subsequent data processing and interpretation, including reducing matrix effects. • Multiple linear regression has proven to be an effective calibration strategy to tackle interference in soil carbon analysis. Further “non-traditional calibration strategies”[68] may be applied, which explore the plasma physicochemical properties, use of analyte emission lines/transition energies with different sensitivities, accumulated signal intensities, and multiple standards to obtain a linear model or calibration curve. • Useful techniques for spectra pre-treatment include partial least squares analysis, artificial neural networks, and removing the interference of iron and aluminum. • Multiple laser shots per sample may improve the measurement results.

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[67] Also known as neutron-stimulated gamma ray analysis or spectroscopy.

[68] Described in Fernandes Andrade et al. (2021) and Costa et al. (2020).

Method	Criteria and Considerations to Ensure Robustness and Reliability
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 and crushed or sieved to a size fraction smaller than 2 mm. - Measurement protocols must be used where 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[69] or new site-specific libraries developed with local soil samples and higher accuracy. Sub-setting or stratifying the dataset may 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.

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

INS

Izaurralde, R. C., Rice, C. W., Wielopolski, L., Ebinger, M. H., Reeves III, J. B., Thomson, A. M., Harris, R., Francis, B., Mitra, S., Rappaport, A. G., Etchevers, J. D., Sayre, K. D., Govaerts, B., & McCarty, G. W. (2013). Evaluation of three field-based methods for quantifying soil carbon. *PLoS ONE*, *8*(1), Article e55560. https://doi.org/10.1371/journal.pone.0055560

Kavetskiy, A., Yakubova, G., Prior, S. A., & Torbert, H. A. (2017). Neutron-stimulated gamma ray analysis of soil. In A. M. Maghraby (Ed.). *New insights on gamma rays*. Intech Open. Available at: https://www.intechopen.com/books/new-insights-on-gamma-rays/neutron-stimulated-gamma-ray-analysis-of-soil

Yakubova, G., Kavetskiy, A., Prior, S. A., & Torbert, H. A. (2019). Application of neutron-gamma analysis for determining compost C/N ratio. *Compost Science & Utilization*, *27*(3), 146–160. https://doi.org/10.1080/1065657X.2019.1630339

LIBS

Castro, J. P., & Pereira-Filho, E. R. (2016). Twelve different types of data normalization for the proposition of classification, univariate and multivariate regression models for the direct analyses of alloys by laser-induced breakdown spectroscopy (LIBS). *Journal of Analytical Atomic Spectrometry*, *31*(10), 2005–2014. https://doi.org/10.1039/C6JA00224B

Costa, V. C., Babos, D. V., Castro, J. P., Fernandes Andrade, D., Gamela, R. R., Machado, R. C., Sperança, M. A., Araújo, A. S., Garcia, J. A., & Pereira-Filho, E. R. (2020). Calibration strategies applied to laser-induced breakdown spectroscopy: A critical review of advances and challenges. *Journal of the Brazilian Chemical Society*, *31*(12), 2439–2451.

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[69] 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 and the Australian soil visible near infrared spectroscopic database described in Viscarra Rossel and Webster (2012)

Fernandes Andrade, D., Pereira-Filho, E. R., & Amarasiriwardena, D. (2021). Current trends in laser-induced breakdown spectroscopy: A tutorial review. *Applied Spectroscopy Reviews*, *56*(2), 98–114. https://doi.org/10.1080/05704928.2020.1739063

Fu, X., Duan, F. J., Huang, T. T., Ma, L., Jiang, J. J., & Li, Y. C. (2017). A fast variable selection method for quantitative analysis of soils using laser-induced breakdown spectroscopy. *Journal of Analytical Atomic Spectrometry*, *32*(6), 1166–1176. https://doi.org/10.1039/C7JA00114B

Milori, D. M. P. B., Segnini, A., da Silva, W. T. L., Posadas, A., Mares, V., Quiroz, R., & Martin-Neto, L. (2011). *Emerging techniques for soil carbon measurements*. CCAFS Working Paper 2. CCAFS. Available at: https://hdl.handle.net/10568/10279

Nicolodelli, G., Marangoni, B. S., Cabral, J. S., Villas-Boas, P. R., Senesi, G. S., Dos Santos, C. H., Romano, R. A., Segnini, A., Lucas, Y., Montes, C. R., & Milori, D. M. B. P. (2014). Quantification of total carbon in soil using laser-induced breakdown spectroscopy: A method to correct interference lines. *Applied Optics*, *53*(10), 2170–2176. https://doi.org/10.1364/AO.53.002170

Segnini, A., Pereira Xavier, A. A., Otaviani-Junior, P. L., Ferreira, E. C., Watanabe, A. M., Sperança, M. A., Nicolodelli, G., Villas-Boas, P. R., Anchão Oliveira, P. P., & Milori, D. M. B. P. (2014). Physical and chemical matrix effects in soil carbon quantification using laser-induced breakdown spectroscopy. *American Journal of Analytical Chemistry*, *5*(11), 722–729. https://doi.org/10.4236/ajac.2014.511080

Senesi, G. S., & 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*, 7–17. https://doi.org/10.1016/j.aca.2016.07.039

Villas-Boas, P. R., Franco, M. A., Martin-Neto, L., Gollany, H. T., & Milori, D. M. B. P. (2020). Applications of laser-induced breakdown spectroscopy for soil analysis, part I: Review of fundamentals and chemical and physical properties. *European Journal of Soil Science*, *71*(5), 789–804. https://doi.org/10.1111/ejss.12888

Villas-Boas, P. R., Franco, M. A., Martin-Neto, L., Gollany, H. T., & Milori, D. M. B. P. (2020). Applications of laser-induced breakdown spectroscopy for soil characterization, part II: Review of elemental analysis and soil classification. *European Journal of Soil Science*, *71*(5), 805–818. https://doi.org/10.1111/ejss.12889

MIR and (Vis-)NIR, including DR and DRIFT spectroscopy

Barthès, B. G., & Chotte, J. L. (2021). Infrared spectroscopy approaches support soil organic carbon estimations to evaluate land degradation. *Land Degradation & Development*, *32*(1), 310–322. https://doi.org/10.1002/ldr.3718

Dangal, S. R. S., Sanderman, J., Wills, S., & Ramirez-Lopez, L. (2019). Accurate and precise prediction of soil properties from a large mid-infrared spectral library. *Soil Systems, 3*(1), Article 11. https://doi.org/10.3390/soilsystems3010011

England, J. R., & Viscarra Rossel, R. A. (2018). Proximal sensing for soil carbon accounting. *SOIL*, *4*(2), 101–122. https://doi.org/10.5194/soil-4-101-2018

FAO (2022). *A primer on soil analysis using visible and near-infrared (vis-NIR) and mid-infrared (MIR) spectroscopy*. FAO. https://doi.org/10.4060/cb9005en

Ng, W., Minasny, B., Jones, E., & McBratney, A. (2022). To spike or to localize? Strategies to improve the prediction of local soil properties using regional spectral library. *Geoderma*, *406*, Article 115501. https://doi.org/10.1016/j.geoderma.2021.115501

Nocita, M., Stevens, A., van Wesemael, B., Aitkenhead, M., Bachmann, M., Barthès, B., Dor, E. B., Brown, D. J., Clairotte, M., Csorba, A., Dardenne, P., Demmatê, J. A. M., Genot, V., Guerrero, C., Knadel, M., Montanarella, L., Noon, C., Ramirez-Lopez, L., Robertson, J., ..., Wetterlind, J. (2015). Soil spectroscopy: An alternative to wet chemistry for soil monitoring. In D. L. Sparks (Ed.). *Advances in Agronomy* (pp. 139–159). Academic Press. https://doi.org/10.1016/bs.agron.2015.02.002

Reeves III, 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*(1–2), 3–14. https://doi.org/10.1016/j.geoderma.2009.04.005

Sanderman, J., Savage, K., & Dangal, S. R. S. (2020). Mid-infrared spectroscopy for prediction of soil health indicators in the United States. *Soil Science Society of America Journal*, *84*(1), 251–261. https://doi.org/10.1002/saj2.20009

Seybold, C. A., Ferguson, R., Wysocki, D., Bailey, S., Anderson, J., Nester, B., Schoeneberger, P., Wills, S., Libohova, Z., Hoover, D., & Thomas, P. (2019). Application of mid-infrared spectroscopy in soil survey. *Soil Science Society of America Journal*, *83*(6), 1746–1759. https://doi.org/10.2136/sssaj2019.06.0205

Stevens, A., Nocita, M., Tóth, G., Montanarella, L., & van Wesemael, B. (2013). Prediction of soil organic carbon at the European scale by visible and near infrared reflectance spectroscopy. *PLoS ONE*, *8*(6), Article e66409. https://doi.org/10.1371/journal.pone.0066409

Viscarra Rossel, R. A., Behrens, T., Ben-Dor, E., Brown, D. J., Demmatê, J. A. M., Shepherd, K. D., Shi, Z., Stenberg, B., Stevens, A., Adamchuk, V., Aïchi, H., Barthès, B. G., Bartholomeus, H. M., Bayer, A. D., Bernoux, M., Böttcher, K., Brodský, L., Du, C. W., Chappell, A., ... Ji, W. (2016). A global spectral library to characterize the world's soil. *Earth-Science Reviews*, *155*, 198–230. https://doi.org/10.1016/j.earscirev.2016.01.012

Viscarra Rossel, R. A., & Webster, R. (2012). Predicting soil properties from the Australian soil visible–near infrared spectroscopic database. *European Journal of Soil Science*, *63*(6), 848–860. https://doi.org/10.1111/j.1365-2389.2012.01495.x

APPENDIX 5: DEFINITIONS OF SOIL SLOPE CLASSES FOR USE IN SETTING BASELINE CONTROL SITES

Table 10: Soil slope classes

Classes for—		Slope (Gradient) Class Limits	
Simple Slopes	Complex Slopes	Lower (%)	Upper (%)
Nearly level	Nearly level	0	3
Gently sloping	Undulating	4	8
Strongly sloping	Rolling	9	16
Moderately steep	Hilly	17	30
Steep	Steep	31	45
Very steep	Very steep	>45	

Adapted from USDA Natural Resource Conservation Service (NRCS) (2017). Chapter 2.—Landscapes, geomorphology, and site description Table 2-3. In: *Soil survey manual handbook no. 18* Available at: https://www.nrcs.usda.gov/resources/guides-and-instructions/soil-survey-manual

Workflow for a Slope Analysis in a GIS

1) Data required: digital elevation model (DEM) as a raster data layer of horizontal and vertical resolution suitable for the extent of the area of interest, and coordinate reference system in meters
2) Tools required: GIS software suitable for processing raster data (e.g., QGIS, ArcGIS, SAGA GIS, GRASS, GDAL)
3) Load the DEM data layer onto the software.
4) Construct a slope (in percent) layer from the DEM.
5) Reclassify the slope layer into discrete slope classes using the class limits listed in Table 10~~Table 10~~.
6) Determine the coverage of – or, equivalently, the number of pixels occupied by – each slope class and identify the dominant slope class (i.e., the slope class with the largest coverage or highest number of pixels occupied).

APPENDIX 6: ADDITIONAL UNCERTAINTY EXAMPLES

Staged sampling designs and alternative measurement approaches are valid and may be applied under this methodology, but stratified random sampling is the required sampling strategy at the stage during which sample points are selected (see Section 8.2.1). In this appendix, an example based on a multi-stage design for a grouped project with multiple landowners with multiple fields is provided. At the final stage, the sampling points are determined randomly within predefined strata, thus following the stratified random sampling strategy.

In such projects, landowners and fields may be dispersed across large geographic areas. Aggregating these fields into a total project area that is then simply divided into strata may prove inefficient and may provide a poor estimate of uncertainty. It would likely result in small numbers of samples being placed in each field, underestimating small-scale variability of change in carbon within fields. Furthermore, since the field is the level at which improved management is typically implemented, ensuring that fields are represented as quantification units within the sampling design may be more appropriate.

In this example design, the stages/units are as follows:

1) Landowner, presuming they have multiple fields enrolled in a project that have the same baseline and project scenarios and similar physical conditions
2) Fields, selected using a probability proportional to size (with replacement) procedure
3) Within-field strata, designed based on physical (e.g., topographic indices) or soil data (e.g., clay content)
4) Points, selected within strata using simple random sampling (with replacement)

The same sources of error apply in this example as in the examples provided in Section 8.6, but the uncertainty estimator for sampling error should be changed to match this alternative design. Below are similar sets of equations for both uncertainty estimation approaches allowed under Quantification Approach 1 and the approach under Quantification Approach 2. Additionally, an example is provided under Quantification Approach 2 in which soil spectroscopy methods are used to measure SOC content and the MC simulation method is used to propagate measurement errors from use of these methods through calculations of the uncertainty deduction.

Quantification Approach 1 – Analytical Error Propagation

$$s^2_{sampling,\Delta\bullet,t} = \sum_{f=1}^{F} s^2_{sampling,\Delta\bullet,f,t} \tag{A6.1}$$

$$s^2_{sampling,\Delta\bullet,f,t} = \frac{1}{k_f\left(k_f - 1\right)}\sum_{j=1}^{k_f}(\Delta \bullet^*_{fj} - \Delta \bullet^*_{f})^2$$

Note – notation for time period t *is suppressed hereafter for convenience.*

Where:

$$\Delta \bullet^*_{fj} = \frac{A_f}{A_{fj}}\sum_{h=1}^{H_{fj}}\frac{A_{fhj}}{n_{fhj}}\sum_{i=1}^{n_{fhj}}\Delta \bullet_{fhji}$$

$$\Delta \bullet^*_{f} = \frac{1}{k_f}\sum_{j=1}^{k_f}\Delta \bullet^*_{fj}$$

and:

$s^2_{sampling,\Delta\bullet,t}$ = Variance of reductions or removals in gas or pool • due to sampling error at time *t* across the entire project area (t CO_2e)^2

$s^2_{sampling,\Delta\bullet,f,t}$ = Variance of reductions or removals in gas or pool • due to sampling error for farmer *f* (i.e., the primary quantification unit) at time *t* (t CO_2e)^2

$\Delta \bullet^*_{fj}$ = Estimated reduction or removal in gas or pool • for farmer *f* across their total land area based on data collected at time *t* in field *j* (t CO_2e)

$\Delta \bullet^*_{f}$ = Average estimated reduction or removal in gas or pool • for farmer *f* across their total land area based on data collected at time *t* across all fields *k* (t CO_2e)

$\Delta \bullet_{fhji}$ = Estimated reduction or removal in gas or pool • in year *t* at point *i* on an area basis in stratum *h* in field *j* for farmer *f* (t CO_2e/ha)

h = 1, …, H_{fj} strata in field *j* for farmer *f*

i = 1, …, n_{fhj} sample points within stratum *h* and field *j* for farmer *f*

j = 1, …, k_f fields selected for sampling for farmer *f*

f = 1, …, *F* farmers in the project

A_{fhj} = Area of stratum *h* in field *j* for farmer *f*

A_{fj} = Area of field *j* for farmer *f*

A_f = Total area for farmer *f*

Model errors are assumed to be uncorrelated with the input data in the sample and to be independent across samples. Then, the variance of $\overline{\Delta \bullet_t}$ incorporating sample uncertainty and model prediction uncertainty is the sum of variances due to sampling and model error divided by the square of the total project area:

$$s^2_{\Delta\bullet,t} = \frac{s^2_{sampling,\Delta\bullet,t}}{A^2} + s^2_{model} \qquad \text{(A6.2)}$$

Quantification Approach 1 – Monte Carlo Error Propagation

Similar to the MC error propagation example provided in Section 8.6.1.2, both model prediction error and sampling error are estimated from a set of *L* estimates of the true total GHG emissions across the entire project. For convenience, introductory text from Section 8.6.1.2 is included here again. Likewise, notation in this section differs from the rest of the methodology to better match conventions in Bayesian statistics. Notation to denote time t is suppressed for convenience and to avoid confusion with the use of τ.

For a particular time period and emission source, the estimand, or target parameter of interest, is the true total reductions and removals across the entire project, denoted as τ, in tonnes of carbon dioxide equivalent (t CO_2e). The estimate of τ produced through MC simulation is denoted by $\hat{\tau}$. Similarly, the areal mean reductions and removals is denoted by μ (equivalent to $\Delta\bullet_t$) in t CO_2e/unit area. Estimates of μ are denoted as $\hat{\mu}$. Since model prediction error is implicitly incorporated into the MC simulations through parameter uncertainty, these estimates may then be used to estimate sampling and model prediction error based on the realized sample s and the sampling design employed.

First, to generate an estimate ($\hat{\tau}$) of τ, GHG emissions are simulated under the baseline and project scenarios multiple times at each sample point, indexed by l = 1, ..., L. The reductions and removals at each point are then calculated as the difference between predicted reductions and removals under baseline and project scenarios. These estimates are used to produce an estimate of reductions and removals ($\tilde{y}$) at each point, similarly indexed by l following Equation (A6.3) below.

$$\tilde{y}_{fjhil} = \tilde{z}_{bsl,fhjil} - \tilde{z}_{pr,fhjil} \qquad \text{(A6.3)}$$

Where:

$\tilde{y}_{fhjil}$ = Predicted reductions and removals for the lth simulation at point *i* in stratum *h* in field *j* for farmer *f* (t CO_2e/ha)

$\tilde{z}_{bsl,fhjil}$ = Predicted reductions and removals in the baseline scenario for the lth simulation at point *i* in stratum *h* in field *j* for farmer *f* (t CO_2e/ha)

$\tilde{z}_{pr,fhjil}$ = Predicted reductions and removals in the project scenario for the lth simulation at point *i* in stratum *h* in field *j* for farmer *f* (t CO_2e/ha)

Note – notation for the source of emissions and time period is suppressed. The sign convention is that $\tilde{z}_{bsl,fjhil}$ *is emissions to the atmosphere in the baseline scenario. Thus, for the SOC pool,* $\tilde{z}_{bsl,fjhil}$ *is* -1

times the predicted temporal change in SOC stocks in the baseline scenario; similarly, $\tilde{z}_{pr,fjhil}$ *is* -1 *times the predicted temporal change in the project scenario.*

The total set of L estimates of $\tilde{y}$ are then used to produce $\hat{t}$ and $\hat{\mu}$, according to Equation (A6.4).

$$\hat{\mu} = \frac{\hat{\tau}}{A}$$

$$\hat{\tau} = \sum_{f=1}^{F} \hat{\tau}_f \qquad \text{(A6.4)}$$

Where:

$$\hat{\tau}_f = \frac{1}{k_f} \sum_{j}^{k_f} \hat{\tau}_{fj}$$

$$\hat{\tau}_{fj} = \frac{A_f}{A_{fj}} \sum_{h=1}^{H_{fj}} \frac{A_{fhj}}{n_{fhj}} \sum_{i=1}^{n_{fjh}} \frac{1}{L} \sum_{l=1}^{L} \tilde{y}_{fhjil}$$

and:

$\hat{\tau}_f$ = Monte Carlo estimate (MC mean) of reductions and removals for a given source for farmer *f* (t CO$_2$e)

$\hat{\tau}_{fj}$ = Monte Carlo estimate (MC mean) of reductions and removals for a given source in field *j* for farmer *f* (t CO$_2$e)

$\hat{\tau}_{fhjil}$ = Monte Carlo estimate (MC mean) of reductions and removals for a given source in field j for farmer f (t CO2e) scaled to their total land area (A-f) in the lth simulation (t CO$_2$e)

The total uncertainty is then decomposed into two components, sampling and modeling uncertainty. Using standard variance decomposition (i.e., the law of total variance) following Del Grosso et al. (2010), the total variance is decomposed according to Equation (A6.5).

$$\mathrm{Var}(\hat{\tau}) = \mathbb{E}[\mathrm{Var}(\hat{\tau}|\boldsymbol{s})] + \mathrm{Var}(\mathbb{E}[\hat{\tau}|\boldsymbol{s}]) \qquad \text{(A6.5)}$$

For the stratified random sampling design used in this example, the variance components are estimated according to Equation (A6.6), which is area-weighted.

$$\widehat{Var}(\hat{\tau}) = \left\{ \sum_{f=1}^{F} s^2_{sampling,f} \right\} + s^2_{model} \qquad \text{(A6.6)}$$

Where:

$$s_{sampling,f}^{2} = \frac{A_f^2}{k_f\left(k_f - 1\right)}\sum_{j=1}^{k_f}(\hat{\tau}_{fj} - \hat{\tau}_f)^2$$

$$s_{model}^{2} = \frac{1}{L-1}\sum_{l=1}^{L}(\tilde{\tau}_l - \hat{\tau})^2$$

$$\tilde{\tau}_l = \sum_{f=1}^{F}\tilde{\tau}_{fl}$$

Where:

$$\tilde{\tau}_{fl} = \frac{1}{k_f}\sum_{j}^{k_f}\tilde{\tau}_{fjl}$$

$$\tilde{\tau}_{fjl} = \frac{A_f}{A_{fj}}\sum_{h=1}^{H_{fj}}\frac{A_{fhj}}{n_{fhj}}\sum_{i=1}^{n_{fhj}}\tilde{y}_{fhjil}$$

and:

$s_{sampling,f}^{2}$ = Variance of reductions and removals in gas or pool • due to sampling error for farmer *f* (i.e., the primary quantification unit) at time *t* (t CO_2e)^2

$\tilde{\tau}_l$ = Monte Carlo estimate (MC mean) of reductions and removals for a given source across the entire project area in the lth simulation (t CO_2e)

$\tilde{\tau}_{fl}$ = Monte Carlo estimate (MC mean) of reductions and removals for a given source for farmer *f* in the lth simulation (t CO_2e)

$\tilde{\tau}_{fjl}$ = Monte Carlo estimate (MC mean) of reductions and removals for a given source in field *j* for farmer *f* in the lth simulation (t CO_2e)

$\tilde{\tau}_{fhjl}$ = Monte Carlo estimate (MC mean) of reductions and removals for a given source in field j for farmer f (t CO2e) scaled to their total land area (A-f) in the lth simulation (t CO_2e)

Lastly, the variance of the mean reduction or removal $\left(\widehat{\mathrm{Var}}(\hat{\mu})\right)$ is obtained based on Equation (A6.7).

$$\widehat{Var}(\hat{\mu}) = \sum_{f=1}^{F}\left\{\frac{1}{A^2}s_{sampling,f}^{2}\right\} + \left\{\frac{1}{A^2}s_{model}^{2}\right\} \qquad \text{(A6.7)}$$

Quantification Approach 2

The total variance of the estimate of mean SOC stock changes is based on the sum of variances of comparisons of project and baseline control plots for each farmer. Variance of SOC removal estimates for each farmer are based on the combined variance of the estimates of change over time in a given verification period *t,* for both the project and baseline scenarios. The covariance of these estimates is conservatively excluded as the baseline control sites and project sites are assumed to be independent. Note that in these equations Δ is used to signify both emission reductions and removals in the SOC pool (i.e., project scenario SOC stocks minus baseline scenario SOC stocks) and changes in SOC stocks over time in both the baseline and project scenarios.

$$s^2_{\overline{\Delta SOC,t}} = \frac{1}{A^2}\sum_{f=1}^{F} s^2_{\Delta SOC,ft} \tag{A6.8}$$

Where:

$$s^2_{\Delta SOC,ht} = s^2_{\Delta SOC,pr,ft} + s^2_{\Delta SOC,bsl,ft}$$

and:

$s^2_{\Delta SOC,ft}$ = Variance of the estimate of total SOC stock changes in verification period *t* for farmer *f*, calculated as the difference in net change between the project and baseline scenarios over period *t* (t CO_2e)^2

$s^2_{\Delta SOC,pr,ft}$ = Variance of the estimate of total SOC stock changes in the project plots in verification period *t* for farmer *f*, calculated as the difference in SOC stocks at the beginning and end of period *t* (t CO_2e)^2

$s^2_{\Delta SOC,bsl,ft}$ = Variance of the estimate of total SOC stock changes in verification period *t* in baseline (control) plots paired with farmer *f*, calculated as the difference in SOC stocks at the beginning and end of period *t* (t CO_2e)^2

Because the sample design for the project and baseline control plots may be different, the uncertainty estimator should match the sample design used in the project and baseline control plots. For example, the project area may be monitored using a staged design if there are a substantial number of quantification units (e.g., fields) in the project area. But the baseline control plots may be fewer, meaning they can all be monitored and would not require a staged design. In such cases, baseline and project areas should use different uncertainty estimators before estimating the combined uncertainty. This example assumes that within each stratum, sample points are similarly determined using simple random sampling with replacement for both baseline and project, so the estimator in both is the same.

Equation (A6.9) provides an example for the project scenario. The variance of the estimate of the change is then a function of the variance and covariance of soil sampling results at both time points within verification period *t*. These time points are denoted as t_{final} and t_{start}, hereafter shortened to subscripts *x* and s.

Note – notation differs from Section 8.6.2 with x *being used instead of* f *to avoid confusion with subscript* f *indicating an individual farmer.*

$$s^2_{\Delta SOC,pr,ft} = s^2_{SOC,pr,fx} + s^2_{SOC,pr,fs} - 2COV(SOC_{pr,fx}\,;\,SOC_{pr,fs}) \tag{A6.9}$$

The variance for an individual farmer is estimated as follows. The same equation form applies to time t_{final}.

$$s^2_{SOC,pr,fs} = \frac{1}{k_f(k_f-1)}\sum_{j=1}^{k_f}(SOC^*_{pr,fsj} - SOC^*_{pr,fs})^2$$

$$SOC^*_{pr,fsj} = \frac{A_f}{A_{fj}} \sum_{h=1}^{H_{fj}} \frac{A_{fhsj}}{n_{fhsj}} \sum_{i=1}^{n_{fhsj}} SOC_{pr,fhsji}$$

$$SOC^*_{pr,fs} = \frac{1}{k_f} \sum_{j=1}^{k_f} SOC^*_{pr,fsj}$$

$$COV\left(SOC_{pr,fs}\,;\,SOC_{pr,fx}\right) = \frac{1}{k_f\left(k_f - 1\right)} \sum_{j=1}^{k_f} (SOC^*_{pr,fsj} - SOC^*_{pr,fs})\,(SOC^*_{pr,fxj} - SOC^*_{pr,fx})^2$$

and:

$s^2_{SOC,pr,fx}$ = Variance of the estimate of SOC stocks in the project scenario at t_{final} for farmer *f* (t CO_2e)^2

$s^2_{SOC,pr,fs}$ = Variance of the estimate of SOC stocks in the project scenario at t_{start} for farmer *f* (t CO_2e)^2

$COV(SOC_{pr,fs}\,;SOC_{pr,fx})$ = Covariance of estimates of SOC stocks at t_{final} and t_{start} in the project scenario for farmer *f* (t CO_2e)^2

$SOC^*_{pr,fsj}$ = Estimated SOC stocks for farmer *f* across their total land area based on data collected at t_{start} for farmer *f* in field *j* (t CO_2e)

$SOC^*_{pr,fs}$ = Mean estimated SOC stocks for farmer *f* across their total land area based on data collected at t_{start} for farmer *f* across all fields *k* (t CO_2e)

SOC_{fhsji} = Estimated SOC stock equivalent at point *i* in stratum *h* in field *j* for farmer *f* at t_{start} (t CO_2e)

A_{fhsj} = Area of stratum *h* in field *j* for farmer *f* at t_{start}

DOCUMENT HISTORY

Version	Date	Comment
v1.0	19 Oct 2020	Initial version
v2.0	30 May 2023	• Introduction of a baseline control sites option to allow for direct SOC measurement under Quantification Approach 2 • Update of Section 8.6 on uncertainty assessment to clarify statistical procedures and align with the *VCS Methodology Requirements* • Introduction of guidance on the use of proximal sensing technologies to estimate SOC content in Appendix 4 • Introduction of an applicability condition in Section 4 and Appendix 2 allowing for one-time land conversion from grassland to cropland or vice versa to restore degraded lands • Introduction of a requirement and procedures to account for emissions associated with use of agricultural limestone in Section 8.2.4 • Introduction of a requirement to account for leakage from diversion of biomass residues used for energy applications in the baseline scenario • General improvements, errata, and clarifications
v2.1	11 September 2024	Minor revision, including the following changes: • Separation of GHG emission reductions and carbon dioxide removals under Section 8 • Title updated to *VM0042 Improved Agricultural Land Management* • Incorporation of the Corrections and Clarifications published on 25 January 2024 ○ The corrections pertain to equations and parameters using default factors to quantify carbon dioxide, methane, and nitrous oxide emissions from diverse ALM activities. ○ The clarifications relate to the following: ▪ Data used to demonstrate common practice ▪ Requirements for soil sampling and analysis ▪ Definitions of quantification units and strata ▪ Evidence that project proponents must provide to comply with various methodology requirements ▪ Explanations of equation parameters ▪ Requirements that are cross-referenced between *VM0042* and *VMD0053*
v2.2	21 October 2025	Minor revision, including the following changes: • Additionality: ○ Replace Step 2 with Step 2 from *VT0008* ○ Replace Step 3 with Step 3.1 determining if the project activity has below 20% adoption in the project region and

		Step 3.2 equivalent to Step 4c of *VT0008* when stacked practices include a practice with an adoption rate >20% ○ Added a justification for setting the 20% adoption rate as a common practice threshold • Added justification for determining the baseline scenario as continuation of pre-project practices. • Added clarifying text for how to select the most conservative EF and disaggregated values when using QA3. • Replace Section 8.4.3 on leakage from productivity declines by *VMD0054.* • Recommend baseline reassessment every five years, wherever possible. • Incorporation of the Corrections and Clarifications published on 10 October 2025 to allow the use of *VT0014* to monitor SOC stock changes via digital soil mapping and requiring the use of templates for supporting documents, available on the *VM0042* webpage