VCS Methodology

VM0042

METHODOLOGY FOR IMPROVED AGRICULTURAL LAND MANAGEMENT

Version 2~~1~~.0

~~19 October 2020~~21 December 2021

Sectoral Scope 14

Version 1.0 of this ~~This~~ methodology was developed by **TerraCarbon LLC** and **Indigo Ag**. The lead authors were David Shoch and Erin Swails from TerraCarbon. Contributions from Indigo ~~would like to acknowledge the many contributions by colleagues at Indigo Ag~~ were made by (in alphabetical order): Chris Black, Charlie Brummit, Nell Campbell, Max DuBuisson, Dan Harburg, Lauren Matosziuk, Melissa Motew, Guy Pinjuv, and Ed Smith. Version 1.0 was approved on 19 October 2020.

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Version 2.0 of this methodology was prepared by Verra staff. Revisions to the uncertainty section were prepared by **Dr. Brian McConkey**, Chief Scientist, Viresco Solutions and **Dr. Beth Ziniti**, Research Scientist, Applied Geosolutions. ~~Indigo would like to acknowledge the many contributions by colleagues at Indigo Ag (in alphabetical order): Chris Black, Charlie Brummit, Nell Campbell, Max DuBuisson, Dan Harburg, Lauren Matosziuk, Melissa Motew, Guy Pinjuv, and Ed Smith. We would like to recognize the valuable input and guidance from Ken Newcombe at C-Quest Capital, as well as the many rounds of detailed review from the experts at Aster Global Environmental Services during the independent methodology validation process. Finally, we thank our reviewers, especially the VCS Agricultural Land Management Working Group, whose comments and suggestions contributed to greatly increase the clarity and effectiveness of this methodology.~~

CONTENTS

1 SOURCES

This methodology is based on the following methodologies:

- *VM0017 Adoption of Sustainable Agricultural Land Management*
- *VM0022 Quantifying N2O Emissions Reductions in Agricultural Crops through Nitrogen Fertilizer Rate Reduction*
- *VM0026 Sustainable Grassland Management*

This methodology uses the latest versions of the following CDM tools:

- *Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities*
- *Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands*
- *Tool for testing significance of GHG emissions in A/R CDM project activities*

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

This Agricultural Land Management (ALM) methodology provides procedures to estimate the greenhouse gas (GHG) emission reductions and removals resulting from the adoption of improved agricultural land management practices focused on increasing soil organic carbon (SOC) storage. The methodology quantifies net emissions of CO_2, CH_4, and N_2O from grower operations. The methodology is compatible with regenerative agriculture.

The baseline scenario assumes the continuation of pre-project agricultural management practices. ~~For regions w~~Where~~where~~ an applicable performance benchmark has been approved by Verra[1], that benchmark ~~must~~ may be applied as the baseline scenario for SOC stocks. Where an applicable performance benchmark has not been approved by Verra~~. Otherwise, for each sample unit within the project area (e.g., for each field)~~, practices applied in the baseline scenario are determined applying a 3-year historic~~historica~~l look-back period to produce an

[1] Such performance benchmarks currently (as of the date of publication) do not exist but may be developed and approved by Verra in the future. If following Quantification Approach 1 (Measure and Model), the performance benchmark developed and approved by Verra will need to include a defined modeled approach that allows for validating model performance and -prediction error for use in the project domain, based on the requirements presented in the "VMD0053 Model Calibration, Validation, and Uncertainty Guidance for the Methodology for Improved Agricultural Land Management~~Model calibration, validation, and uncertainty guidance for the methodology for improved agricultural land management~~" ~~document~~module.

annual schedule of activities (i.e., ~~.g.,~~ tillage, planting, harvest, and fertilization events) for each sample unit within the project area (e.g., for each field) to be repeated over the first ~~baseline~~ crediting period. Baseline emissions/stocks change are then modeled. Alternately, 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 *VCS Standard*, and revised, if necessary, to reflect current agricultural production in the region.

Additionality is demonstrated by the adoption, at the project start date, of one or more changes in pre-existing agricultural management practices. A practice change constitutes adoption of a new practice (e.g., adoption of one or more of the practices covered in the categories included in ~~the~~ applicability condition~~s~~ 1~~as well as the illustrative improved agricultural land management practices listed in Appendix 1~~), cessation of a pre-existing practice (e.g., stop tillage or irrigation), adjustment to a pre-existing practice, or some combination thereof. Any quantitative adjustment (e.g., decrease in fertilizer application rate) must exceed 5% of the pre-existing value to demonstrate additionality.

Table 1: Additionality and Crediting Baseline Methods

Additionality and Crediting Method	
Additionality	Project Method
Crediting Baseline	Project Method

The methodology provides three ~~a flexible~~ approach~~approach~~es to quantifying emission reductions and removals resulting from the adoption of improved agricultural land management practices: ~~under the following quantification approaches:~~

- **Quantification Approach 1:** Measure and Model – an acceptable model is used to estimate GHG flux based on edaphic characteristics and actual agricultural practices implemented, measured initial SOC stocks, and climatic conditions in sample fields.
- **Quantification Approach 2:** Measure and Re-measure – direct measurement is used to quantify changes in SOC stocks. This approach is relevant where models are unavailable or have not yet been validated or parameterized for a particular region, crop, or practice. ~~Currently,~~ Quantification Approach 2 ~~cannot be used because a~~ uses a performance benchmark ~~has not yet been developed~~. If an applicable performance benchmark is not available, SOC stock changes in the baseline scenario are directly measured in linked baseline control sites.
- **Quantification Approach 3:** Calculation – CO_2 flux from fossil fuel combustion and N_2O and CH_4 fluxes, excluding CH_4 flux from methanogenesis, are calculated following *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2019) using equations contained in this methodology.

Quantification approach varies by emission/removal type. Approaches to quantifying ~~ication of contributing sources for~~ CO_2, CH_4, and N_2O emissions are listed in Table 5. Monitoring is conducted for both the baseline and project scenarios. If an applicable performance benchmark is not available, emission/stock changes in the baseline scenario are modeled using Quantification Approach 1, partly ~~on the basis of~~based on one or more monitored input variables (e.g., temperature, precipitation), directly monitored (SOC stock change only) in linked baseline control sites,~~)~~ or calculated using Quantification Approach 3 as detailed in Table 5.

3 DEFINITIONS

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

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

Baseline control site
Defined area that is managed according to pre-project practices as set out in the schedule of activities for direct measurement of baseline SOC stock change and is linked to one or more sample units and representative of the land which is subject to a soil carbon project.

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.

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

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

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

Professional agronomist
An individual with specialized knowledge, skill, education, experience, or training in crop and/or soil science.

Project domain

Set of conditions (including crop type, soil texture and climate) within which model application has been validated (see VMD0053 “Model Calibration and Validation Guidance for the Methodology for Improved Agricultural Land Management”).

Sample point
Sample location of undefined area.

Sample unit
Defined area that is selected for measurement, modelling if applicable, and monitoring, such as a field or sample point. Sample unit and sample field are used interchangeably in the methodology. The entire project area is divided into sample units that are assumed to be homogenous for the purposes of modelled estimates including those from simple models (i~~I~~.e., equations using emission factors). The estimate of emission effect of the whole project is the total difference in fluxes between project and baseline for the population of all the sample units. For quantification approach 1 (measure and model), the sample unit will be the smallest homogenous unit for which estimates for the flux difference are modeled. Aligning the sample units for modeling to match those for the approved sampling design true-up measurements will give more power for comparing modeled results with the true-up. For quantification approach 2 (measure and re-measure), the sample unit is defined by the sampling design and is the smallest area for which SOC measurements are applied to make a single estimate of SOC for that sample unit. When a stratified random sampling is used, the sample units will be the strata, if grid sampling is used, the sample unit will be the grid cells, and if simple random sampling of fields is used, the sample units will be the fields.

Schedule of Activities
Annual schedule of historical management/activity practices applied in the baseline scenario over the historical look-back period (~~i.e~~e.g., tillage, planting, harvest, and fertilization events). These practices are based on data requirements of Box 1 repeated over the baseline period and apply to relevant model input variables (see Table 6 and Table 8~~ Tables 4 and 7~~) and parameters $FFC_{bsl,j,i,t}$, $P_{bsl,l,i,t}$, $Days_{bsl,l,i,t}$, $M_{bsl,SF,i,t}$, $M_{bsl,OF,i,t}$, and $MB_{g,bsl,i,t}$, etc.

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

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

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

4 APPLICABILITY CONDITIONS

This methodology is global in scope and applies to a broad range of agricultural management project activities that increase soil organic carbon storage and/or decrease net emissions of CO2, CH4, and N2O from grower operations compared to the baseline scenario.

This methodology is applicable under the following conditions:

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

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

   See Appendix 1 for additional details ~~on these practices~~and guidance on practices and on determining practice change.

2. Project activities must be implemented on land that is either cropland or grassland at the project start date and remains cropland or grassland throughout the project crediting period ~~(i.e., land use change is not eligible, including conversion from cropland to grassland and grassland to cropland)~~. However, land use change (i.e., conversion from cropland to grassland or vice versa) may be allowed under the following scenarios:
   - Introduction of temporary grassland into cropland is allowed where it can be credibly demonstrated prior to project validation that the integration of perennial crops (e.g., grasses, legumes) into annual crops is planned as part of a long-term agricultural management system (~~i.~~e.g., Integrated Crop-Livestock System~~integrated crop-livestock system)~~) . In this case, projects must provide documentation on the long-term management plans that cover the duration of the proposed project.

- Conversion from grassland to cropland or vice versa where it can be credibly demonstrated prior to project validation that project lands in the baseline scenario are degraded and the introduction of improved practices involving land use change would lead to significant improvements in soil health and associated socioenvironmental benefits. In this case, projects must provide documentation demonstrating that lands are degraded at the start of the project and degradation will continue in the baseline scenario due to the presence of degradation drivers or pressures in the baseline scenario. See Appendix 2 for procedures on how to propose this type of land use change.

~~2.~~3. The project area must not have been cleared of native ecosystems within the 10-year period prior to the project start date.

~~3.~~4. The project activity is not expected to result in a sustained reduction of greater than 5%[2] in productivity, as demonstrated by peer-reviewed and/or published studies on the activity in the region or a comparable region.

~~If the project activity involves the application of biochar, it must be produced using feedstock that would otherwise have been left to decay in aerobic or anaerobic conditions or been burned in an uncontrolled manner. Eligible feedstocks include one or more of the following categories of biomass:~~

~~Crop residues;~~

~~Material from pruning or thinning of woody vegetation (not including merchantable timber) in agricultural systems such as shade trees, orchards, windbreaks, stream buffers, silvopasture, or invasive removal on rangeland;~~

~~Off cuts, sawdust, and other material produced as a by-product of forest management or harvesting operations;~~

~~Diseased trees or deadwood felled during plantation or woodland management; and/or~~

~~Residential, commercial, or industrial organic food or yard waste.~~

~~There may not be any other carbon incentive awarded for the production of biochar applied on the project area.[3]~~

This methodology is not applicable under the following conditions:

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[2] 5% is the ~~*VCS Methodology Requirements*~~ threshold for emissions that can be considered *de minimis* *(see VCS Methodology Requirements v4.0, Section 3.3.6).*~~.~~

~~[3] For projects seeking to credit biochar activities, Verra will soon publish a methodology for biochar projectswhich is available at https://verra.org/methodology/methodology-for-biochar-utilization-in-soil-and-non-soil-applications/.~~

1. The project activity cannot occur on a wetland. Note that this condition does not exclude crops subject to artificial flooding where it can be demonstrated that crop cultivation does not impact the hydrology of any nearby wetlands.

2. The project activity cannot include application of biochar as a soil amendment.[4]

Additional conditions where models are applied:

The methodology does not mandate the use of any specific model. Rather, this methodology is applicable where empirical or process-based models used to estimate stock change/emissions meet specific conditions. Models must be:

1. Publicly-available~~;~~, though not necessarily free of charge, from a reputable and recognized source (e.g., the model developer's website, IPCC or government agency)~~;~~
2. Shown in peer-reviewed scientific studies to successfully simulate changes in soil organic carbon and trace gas emissions resulting from changes in agricultural management included in the project description;
3. Able to support repetition of the project model simulations. This includes clear versioning of the model use in the project, stable software support of that version, as well as fully reported sources and values for all parameters used with the project version of the model. Where multiple sets of parameter values are used in the project, full reporting includes clearly identifying the sources of varying parameter sets as well as how they were applied to estimate stock change/emissions in the project. Acceptable sources include peer-reviewed literature and statements from appropriate expert groups (i.e., that can demonstrate evidence of expertise with the model via authorship on peer-reviewed model publications or authorship of reports for entities supporting climate smart agriculture, such as FAO or a comparable organization), and must describe the data sets and statistical processes used to set parameter values (i.e., the parameterization or calibration procedure); and
4. Validated per datasets and procedures detailed in VMD0053 "Model Calibration and Validation Guidance for the Methodology for Improved Agricultural Land Management", with model prediction error calculated using datasets as detailed in the same module, using the same parameters or sets of parameters applied to estimate stock change/emissions in the project.

The same model version and parameters/parameter sets must be used in both the baseline and project scenarios. Model input data must be derived following guidance in Table 6~~Table 6~~ (Section 8.2)~~8.2)~~ and Table 8~~Table 7~~ (Section 8.3).~~8.3).~~ Model uncertainty must be quantified

[4] For projects seeking to credit biochar activities, Verra will soon publish a methodology for biochar projects available at https://verra.org/methodology/methodology-for-biochar-utilization-in-soil-and-non-soil-applications/.

following guidance in Section ~~8.5~~8.6.~~8.5.~~ Models may be recalibrated or revised based on new data, or a new model may be applied, provided the above requirements are met.

5 PROJECT BOUNDARY

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

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

Table 2: Selected Carbon Pools in the Baseline and Project Scenario

Source	Included?	Justification/Explanation
Aboveground woody biomass	Yes / Optional	Aboveground woody biomass must be included where project activities may significantly reduce the pool compared to the baseline. In all other cases aboveground woody biomass is an optional pool. Where included it is calculated using the CDM A/R Tools *Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities* and *Simplified baseline and monitoring methodology for small scale CDM afforestation and reforestation project activities implemented on lands other than wetlands.*
Aboveground non-woody biomass	No	Carbon pool does not have to be included because it is not subject to significant changes, or potential changes are transient in nature, per the VCS rules.
Belowground woody biomass	Optional	This 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.*
Belowground non-woody biomass	No	Carbon pool does not have to be included because it is not subject to significant changes, or potential changes are transient in nature, per the VCS rules.

Dead wood	No	Carbon pool is not included because it is not subject to significant changes or potential changes are transient in nature, per the VCS rules.
Litter	No	Carbon pool is not included, because it is not subject to significant changes or potential changes are transient in nature, per the VCS rules.
Soil organic carbon	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 per the VCS rules.

GHG sources included in the project boundary in the baseline and project scenarios are listed in Table 3 below. Where the increase in greenhouse gas emissions from any project emissions or leakage source, and/or decreases in carbon stocks in carbon pools, is less than five percent of the total net anthropogenic GHG emission reductions and removals due to the project, such sources and pools may be deemed *de minimis* and may be ignored (i.e., their value may be accounted as zero). This and all subsequent references to *de minimis* demonstration are conducted via application of CDM A/R methodological *Tool for testing significance of GHG emissions in A/R CDM project activities.*[5]

Table 3: GHG Sources Included in or Excluded from the Project Boundary in the Baseline and With Project Scenario

Source	Gas	Included?	Justification/Explanation
Soil organic carbon	CO_2	Yes	Quantified as stock change in the pool, rather than an emissions source (see Table 2).
Fossil fuel	CO_2	S*	The sources of fossil fuel emissions are vehicles (mobile sources, such as trucks, tractors, etc.) and mechanical equipment required by the ALM activity.
Soil methanogenesis	CH_4	S*	
Enteric fermentation	CH_4	Yes	If livestock are present in the project or baseline scenario, CH_4 emissions from enteric

[5] Since project activities may not result in a sustained reduction in productivity (including animal weight gains) or sustained displacement of any preexisting productive activity, feedlots are conservatively not included in the project boundary.

			fermentation must be included in the project boundary.
Manure deposition	CH_4	Yes	If livestock are present in the project or baseline scenario, 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	If in the baseline scenario the project area would have been subject to nitrogen fertilization, or If nitrogen fertilization is greater in the with project scenario relative to the baseline scenario, N2O emissions from nitrogen fertilizers must be included in the project boundary.
Use of nitrogen fixing species	N_2O	Yes	If 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	However, carbon stock decreases due to burning are accounted as a carbon stock change
Biomass burning	CH_4	S*	
	N_2O	S*	
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 may significantly increase emissions compared to the baseline scenario and may be included where the project activity may reduce emissions compared to the baseline scenario.

6 BASELINE SCENARIO

Continuation of pre-project agricultural management practices is the most plausible baseline scenario. For each sample unit (e.g., for each field), practices applied in the baseline scenario are determined applying a historic~~historical~~ look-back period to produce an annual schedule of activities to be repeated over the first ~~baseline~~ crediting period. Baseline emissions/stocks change are then modeled or (for SOC stock change only) directly measured in baseline control sites subject to the annual schedule of activities~~calculated~~. The crops and practices assumed in the baseline scenario are re-evaluated as required by the *VCS* ~~*rules*~~ *Standard* and revised, if necessary, to reflect current agricultural production in the region.

Development of schedule of activities in the baseline scenario

For each sample unit, a schedule of activities in the baseline scenario will be determined by assessment of practices implemented during the period prior to the project start date. The interval over which practices are assessed, x years, must be a minimum of 3 years and include at least one complete crop rotation, where applicable. Where a crop rotation is not implemented in the baseline, x = 3 years.

For each year, t = -1 to t = -x, information on agricultural management practices must be determined, per the requirements presented in Table 4 below. ~~UnitsEmissions fromUnits for fertilizer application rates wilwill be based on either model (Quantification Approach 1) or default (Quantification Approach 3) input requirements.~~ Guidance on sourcing qualitative and quantitative information is provided in Box 1.

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

Agricultural management practice	Qualitative	Quantitative
Crop planting and harvesting	• Crop Type(s)	• Approximate date(s) planted (if applicable) • Approximate date(s) harvested / terminated (if applicable)
Nitrogen fertilizer application	• Manure (Y/N) • Compost (Y/N) • Synthetic N fertilizer (Y/N)	• Manure type application rate (if applicable) • Compost type application rate (if applicable) • N application rate in synthetic fertilizer (if applicable)
Tillage and/or residue management	• Tillage: (Y/N) • Crop residue removal	• Depth of tillage (if applicable) • Frequency of tillage (if applicable) • Percent of soil area disturbed (if applicable) • Percent of crop residue removed (if applicable)

Water management/irrigation	● Irrigation (Y/N) ● Flooding (Y/N)	● Irrigation rate (if applicable)
Grazing practices	● Grazing (Y/N) ● Animal type (if applicable)	● Animal stocking rate, i.e., number of animals and length of time grazing in a given area annually (if applicable)

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

The schedule of activities, beginning with year *t* = -*x*, will be 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 will be valid until re~~-~~evaluation is required by the latest version of the *VCS Standard*. At the end of each ~~baseline~~ crediting period, production of the commercial crop(s) in the baseline scenario will be re-evaluated. Published regional (sub-national) agricultural production data from within the 5-year period preceding the end of the current baseline period must be consulted.

Where there is evidence of continued production of the relevant commercial crop(s) using the same management practices, the baseline scenario will be valid as-is per the VCS rules, 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 agricultural management activities (evaluated against common practices in the region) will be developed ~~on the basis of~~based on written recommendations for the sample field provided by an independent professional agronomist or government agricultural extension agent. Recommendations must provide sufficient detail to produce the minimum specifications on agricultural management practices for the baseline scenario as enumerated in Table 4 above. Where more than one value is documented in recommendations (e.g., where a range of application rates are prescribed in written recommendations), the principle of conservatism must be applied, selecting the value that results in the lowest expected emissions (or highest rate of stock change) in the baseline scenario.

Where the evidence is not field-specific, conservatively derived field-specific values must be supported by a documented method of field-specific values justifying the appropriateness of selection.

7 ADDITIONALITY

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

The project proponent must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the VCS Methodology Requirements (see *VCS Methodology Requirements v4.1*, Section 3.5.3).

In addition to the demonstration of regulatory surplus, project proponent(s) must:

1. Identify barriers that would prevent the implementation of a change in pre-existing agricultural practices; and,

2. Demonstrate that the adoption of the suite of proposed project activities is not common practice.

Further details on each of these steps are provided below.

Step 1: Identify barriers that would prevent the implementation of a change in pre-existing agricultural management practices

The project proponent must determine whether there are barriers (e.g., cultural practices and social norms, attitudes and beliefs) to the proposed change(s) in agricultural management expected to reduce GHG emissions and/or increase GHG removals that prevent the implementation of the change without the intervention of the project proponent and the resulting revenue from the sale of VCUs.

The project proponent must list and describe barriers to implementation of proposed changes to pre-project agricultural management practices to establish that the change would not occur if the project was not undertaken by the project proponent and registered as a VCS project. ~~For example, cultural and/or social barriers related to averting risk in the face of uncertainty (Rodriguez et al. 2009)[6] as well as self-perceived capacity to implement changes (Singh et al. 2016)[7] have been shown to inhibit practice change in the agricultural sector. Further, trust in technical assistance providers is critical for spreading adoption of changes (Carolan 2006)[8] among other factors, such as access to information and increased social networking among growers (Roco et al. 2014)[9].~~For example, cultural and/or social barriers related to averting risk

~~[6] Rodriguez, JM, Molnar, JJ, Fazio, RA, Sydnor, E, Lowe, MJ. 2009. Barriers to adoption of sustainable agriculture practices: Change agent perspectives. *Renewable Agriculture and Food Systems* 24: 60-71.~~

~~[7] Singh, C, Dorward, P, Osbahr, H. 2016. Developing a holistic approach to the analysis of farmer decision-making: Implications for adaptation policy and practice in developing countries. Land Use Policy 59: 329-343.~~

~~[8] Carolan, MS. 2006. Social change and the adoption and adaptation of knowledge claims: Whose truth do you trust in regard to sustainable agriculture? *Agriculture and Human Values* 23: 325-339.~~

~~[9] Roco, L, Engler, A, Bravo-Ureta, B, Jara-Rojas, R. 2014. Farm level adaptation decisions to face climatic change and variability: Evidence from Central Chile. Environmental Science & Policy 44: 86-96.~~

~~in the face of uncertainty (Rodriguez *et al.*, 2009)(Rodriguez et al. 2009)[10] as well as self-perceived capacity to implement changes (Singh, Dorward and Osbahr, 2016) (Singh et al. 2016)[11] have been shown to inhibit practice change in the agricultural sector. Further, trust in technical assistance providers is critical for spreading adoption of changes (Carolan, 2006)(Carolan 2006)[12] among other factors, such as access to information and increased social networking among growers (Roco *et al.*, 2014)(Roco et al. 2014)[13].~~

Demonstration of cultural and/or social barriers must be supported by peer-reviewed and/or published studies~~.~~, which should be specific to the project region. Where such evidence is not available for the project region, evidence from other regions may be used ~~provided that~~if justification is given demonstrating how those cultural and/or social barriers are also applicable in the project region.

Such barriers may include traditional knowledge or lack thereof, laws and customs, market conditions and lack of motivating incentives to change practices, including, but not limited to:

- Traditional equipment and technology;
- Barriers associated with whether growers believe they can feasibly adopt new practices, implications of decisions, and their attitudes towards risk;
- Barriers associated with openness to new ideas and the grower perceptions of the magnitude of the change; and
- Barriers associated with grower identity.

Step 2: Demonstrate that the adoption of the suite of proposed project activities is not common practice

The project proponent must determine whether the proposed project activity or suite of activities[14] are common practice in each region included within the project spatial boundary. Common practice is defined as greater than 20% adoption.[15] To demonstrate that a project activity, or suite of activities, is not common practice, the project proponent must show that the weighted average adoption rate of the three (or more) predominant[16] proposed project

~~[10] Rodriguez, JM, Molnar, JJ, Fazio, RA, Sydnor, E, Lowe, MJ. 2009. Barriers to adoption of sustainable agriculture practices: Change agent perspectives. *Renewable Agriculture and Food Systems* 24: 60-71.~~

~~[11] Singh, C, Dorward, P, Osbahr, H. 2016. Developing a holistic approach to the analysis of farmer decision-making: Implications for adaptation policy and practice in developing countries. Land Use Policy 59: 329-343.~~

~~[12] Carolan, MS. 2006. Social change and the adoption and adaptation of knowledge claims: Whose truth do you trust in regard to sustainable agriculture? *Agriculture and Human Values* 23: 325-339.~~

~~[13] Roco, L, Engler, A, Bravo-Ureta, B, Jara-Rojas, R. 2014. Farm level adaptation decisions to face climatic change and variability: Evidence from Central Chile. Environmental Science & Policy 44: 86-96.~~

[14] The suite of activities refers to all activities implemented across the aggregated project. It does not refer to the activities implemented on each individual farm.

[15] Following the 20% common practice threshold in the CDM *Methodological tool: Common practice* https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-24-v1.pdf.~~https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-24-v1.pdf.~~

[16] Determined based on the extent of the project area (acres or hectares).

activities within the project spatial boundary is below 20%.[17] Therefore, in projects where existing activity (e.g., reduced tillage) adoption rates are >20% the project must include a proportionally higher ratio of other activities with lower adoption rates (e.g., cover crops, improved fertilizer management) to bring the weighted average of proposed project activities below 20%. An individual activity with an existing adoption rate in the relevant region below 20% is always~~is always~~ considered additional. However, an individual activity with an existing adoption rate greater than 20% may only be considered additional through the assessment of the weighted average adoption rate for all project lands within that region.

Categories of project activities for the demonstration of common practice may be defined according to the categories in the evidence provided, or to the categories outlined in Table 4.

Evidence must be provided in the form of publicly available information contained in:

1. Agricultural census or other government (e.g., survey) data;
2. Peer-reviewed scientific literature;
3. Independent research data; or
4. Reports or assessments compiled by industry associations.

The highest-quality available evidence source appropriate to the project must be used. The project area should be ~~divided~~ stratified for the purpose of the common practice demonstration to the state or provincial level (or equivalent 2nd order jurisdiction) in the country(ies) where the project is being developed. If supporting evidence is not available at the state/provincial level (e.g., in developing countries) aggregated data or evidence at a country 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. However, to maintain the integrity of the common practice demonstration, the same stratification approach and data sources should be applied across the entire project. Where a data source is not available for a subset of the project region, justification should be provided as to why a different data source was used.

When evidence on ~~the~~ a single proposed project activity~~, or suite of activities,~~ 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) providing an estimate of the adoption rate for purposes of the weighted average calculation. ~~stating that the proposed project activity, or suite of activities, is not common practice in the region.~~Where evidence on the suite of proposed activities is not

[17] If a project is planning to only implement two activities, common practice must be assessed based on the weighted average of those two activities. If only one activity is implemented, common practice must be assessed solely based on that activity's adoption rate (i.e., the adoption rate of that activity must be below 20%).

available, a qualified independent local expert may provide a signed and dated attestation statement stating that the proposed project activity is not common practice in the region.

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

Equation 1

$$AR = ((EA_{a1\cancel{i}} \times PA_{a1\cancel{i}}) + (EA_{a2} \times PA_{a2}) + \cdots + (EA_{an} \times PA_{an})\ ;\ where$$

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

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

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

Where:

AR	weighted average adoption rate in region; %
EA_{a1}	existing adoption rate of largest (i.e., size of land area) most common proposed project activity in region; %
EA_{a2}	existing adoption rate of second largest most common proposed project activity in region; %
EA_{an}	existing adoption rate of the *n* largest most common proposed project activity in region; %
PA_{a1}	ratio of proposed project-level adoption of Activity $_{a1}$ relative to proposed project-level adoption of Activity $_{a1}$ + Activity $_{a2}$ + … + Activity $_{an}$ in region; unitless
PA_{a2}	ratio of proposed project-level adoption of Activity $_{a2}$ relative to proposed project-level adoption of Activity $_{a1}$ + Activity $_{a2}$ + … + Activity $_{an}$ in region; unitless
PA_{an}	ratio of proposed project-level adoption of Activity $_{an}$ relative to proposed project-level adoption of Activity $_{a1}$ + Activity $_{a2}$ + … + Activity $_{an}$ in region; unitless
$Area_{a1}$	area of proposed project-level adoption of Activity $_{a1}$ in region; hectares or acres
$Area_{a2}$	area of proposed project-level adoption of Activity $_{a2}$ in region; hectares or acres
$Area_{an}$	area of proposed project-level adoption of Activity $_{an}$ in region; hectares or acres
n	project activity category

A project proponent may include areas where more than one project activity will be implemented on the same land (e.g., reduced tillage plus cover crops). Evidence on existing adoption rates for the combined (two or more) activities should be used to calculate the weighted average adoption rate of the proposed combined activities. Where evidence on existing adoption rates for the combined activities is not available, the project proponent may multiply the existing adoption rates (i.e., pre-project) of the individual activities to estimate the combined activity adoption rate.[18] For example, with a statewide existing adoption rate of 40% for reduced-tillage and 10% for cover-cropping, the existing adoption rate to be applied (in the weighted average calculation above) for lands combining (stacking) these two activities would be 4% (i.e., 40% x 10%).

If Step 1 and Step 2 are satisfied, the proposed project activity is additional.

For registered projects with an initial set of project activity instances, Appendix 3 lays out a recommended process for assessing whether new project activity instances are common practice.

8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

8.1 Summary

This methodology provides a flexible approach to quantifying emission reductions and removals resulting from the adoption of improved agricultural land management practices in the project compared to the baseline scenario. Baseline and project emissions are defined in terms of flux of CH_4, ~~and~~ N_2O and CO_2 in units of tonnes of CO_2e per unit area per monitoring period. Within each sample unit, stock changes in each included pool are treated on a per unit area basis in accounting procedures, while changes in emissions are treated as the total change in emissions from each source per sample unit, prior to generating an areal average for the project in Section 8.5.~~8.5.~~ Where a monitoring period crosses multiple calendar years, the equations quantify emission reductions by year (as defined in Section 3)~~3)~~ ~~in order to~~to appropriately define vintage periods.

Approaches to quantification of contributing sources for CO_2, CH_4 and N_2O are listed in Table 5. For a given pool/GHG source, projects must preferentially set the baseline scenario equal to the performance benchmark where an applicable performance benchmark exists. Where more than

[18] In practice, this encourages “stacking” of new activities to enhance GHG reductions and/or removals compared to implementing only one new activity on a given area or farm.

one quantification approach is allowable for a given gas and source, more than one approach may be used, provided that within a given area of the project the same approach is used for both the project and baseline scenarios.

Table 5: Summary of Allowable Quantification Approaches

GHG/Pool	Source	Quantification Approach 1: Measure and Model*	Quantification Approach 2: Measure and Remeasure	Quantification Approach 3: Default
CO_2	Soil organic carbon	X	X	
	Fossil fuel			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
	Biomass burning			X

* Approach 1 may only be used if a valid model is available (see model requirements in VMD0053 "Model Calibration and Validation Guidance for the Methodology for Improved Agricultural Land Management").

** If 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.*

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 crediting period, provided that the same approach is used for both the project and baseline scenario. The quantification approaches are defined as follows:

1. **Quantification Approach 1: Measure and Model**

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

2. **Quantification Approach 2: Measure and Remeasure**

   Relevant where models are unavailable or have not yet been validated or parameterized. Where an applicable performance benchmark exists, the baseline is equal to the performance benchmark. Where an applicable performance benchmark does not exist, the baseline scenario is measured and remeasured directly at a baseline control site linked to one or more sample units. ~~The baseline is set equal to a performance benchmark.~~ Quantification Approach 2 is only applicable to SOC.

   ~~*Note – Currently Quantification Approach 2 cannot be used because a performance benchmark does not exist. Interested stakeholders would be responsible for developing the performance benchmark in accordance with VCS Guidance for Standardized Methods.*Guidance for Standardized Methods. *The creation of a performance benchmark will require a revision to the methodology.*~~

3. **Quantification Approach 3: Calculation**

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

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

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

For projects employing Quantification Approach 1 for the quantification of SOC stock changes, the subsequent direct SOC measurement will be used in the same manner as in the first year of the project, as the input to the model simulation for that year. The output SOC stock from that simulation would then be compared to the output SOC stock from the simulation of the prior monitoring period to determine the SOC stock change, and thereby incorporating any adjustment (i.e., “true-up”) based on the direct measurement.

8.2 Baseline Emissions

Quantification Approach 1

The baseline is modeled for each sample unit. Where an applicable performance benchmark exists, the baseline is equal to the performance benchmark. The model serves to project stock change/emissions resulting from the schedule of agricultural management activities taking place in the baseline scenario (derived above). Further guidance on biophysical model inputs is elaborated in ~~Table 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
Soil organic carbon ~~stock content~~ and bulk density to calculate SOC stocks (initial)	Determined *ex ante*	Directly measured via conventional analytical laboratory methods, e.g., dry combustion, at $t=0$ or (back-) modeled to $t=0$ from measurements collected within +/-5 years of $t=0$, or determined for t=0 via emerging technologies (e.g., INS, LIBS, MIR and Vis-NIR~~remote sensing~~) with known uncertainty following the criteria in Appendix 4. See parameter table for $SOC_{wp,i,t=0}$.
Soil properties (other than bulk density and soil organic carbon)	Determined *ex ante*	Directly measured or determined from published soil maps, with known uncertainty. Estimates from direct measurements must satisfy the following: ● Derived from representative (unbiased) sampling ● Accuracy of measurements is ensured through adherence to best practices.
Climate variables (e.g., precipitation, temperature)	Continuously monitored *ex ante*	Measured for each model-specific meteorological input variable at its required temporal frequency (e.g., daily) model prediction interval. Measurements are taken at the closest ~~continuously-monitored~~continuously monitored weather station,

		not exceeding 50 km of the sample field, or from a synthetic weather station (e.g., PRISM[19]).

Quantification Approach 2

Where a Verra-approved applicable performance benchmark exists, the baseline is equal to the performance benchmark.

Where an applicable performance benchmark does not exist, the baseline may be measured and remeasured directly at baseline control sites which are linked to sample units. Control sites will be managed applying schedules of activities established in the baseline scenario for their corresponding sample unit (derived in Section 6) and will comply with the similarity criteria listed in ~~Table 7~~ Table 7 below. There are no geographic proximity requirements for control sites to their linked sample units (e.g., control sites could be established and managed on a designated experimental farm outside of the project area). It is possible for one control site to be linked to more than one sample unit provided they meet the similarity criteria for those sample units. Furthermore~~.~~, ~~also~~when stratification is applied as a sampling strategy (see section 9.3.1) it is possible that controls sites are linked to individual strata provided they also meet the similarity criteria for each stratum. Control sites must be sufficiently large to ensure that any changes in SOC stocks are driven by baseline management practices, i.e., edge effects should be eliminated. Finally, under this approach at least two control sites are required, but more will decrease uncertainty, particularly when the number is less than 10 – see Section 8.6.2 for further details.

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

Control Site Similarity Criterion	Tier*	Threshold**
Topography	1	Average slope in the same slope class[20] as slope of linked sample unit; aspect within 30° of the cardinal direction of linked sample unit~~.~~
Soil texture to depth of project boundary (initial *t=0*)	1	Average soil texture in the same USDA soil textural class as the average soil texture~~n~~ of linked sample unit

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

[20] See Table 10 in Appendix 5 showing soil slope classifications to apply.

Control Site Similarity Criterion	Tier*	Threshold**
Management activities (including crop types, crop cycles, cover crops, soil amendments, irrigation/hydrological management, tillage and/or grazing)	1	Implemented *ex post* per schedule of activities in the baseline scenario; prior to project start date has reasonably similar historical management for, at minimum, the historical look-back period applied to produce the annual schedule of baseline activities
Percent soil organic carbon as % of dry weight to depth of project boundary (initial *t*=0)	2	Within the uncertainty range (i.e., not significantly different) of average % SOC of linked sample unit
Bulk density g/cm^3 to depth of project boundary (initial *t*=0)	2	Within the uncertainty range (i.e., not significantly different) of linked sample unit
Native vegetation	3	Within the same Terrestrial Ecoregion[21] as the linked sample unit
Climate zone	3	Within the same IPCC-defined climate zone as the linked sample unit

*The similarity criteria are split into tiers by order of importance as follows:

- Tier 1 criteria must be met without exceptions.
- Tier 2 criteria must be met. However, where the uncertainty ranges are exceedingly narrow for control sites and/or linked sample units, slight deviations are allowed with justification.
- Tier 3 criteria should be met where possible. However, differences are allowed with justification.

**For quantitative thresholds listed in Table 7 ~~the table above~~, estimates must be derived from un-biased, representative sampling of the control site, and accuracy ensured through adherence to best practices (to be determined by the project proponent and outlined in the monitoring plan – see Section 9.3.3).

~~*Note – Currently Quantification Approach 2 cannot be used because a performance benchmark does not exist. Interested stakeholders would be responsible for developing the performance benchmark in accordance with* VCS Guidance for Standardized Methods*. The creation of a performance benchmark will require a revision to the methodology.*~~

[21] As defined by the WWF Terrestrial Ecoregions of the World database available for download at https://www.worldwildlife.org/publications/terrestrial-ecoregions-of-the-world and described in Olson et al 2001.

Quantification Approach 3

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

Calculation flow is summarized in ~~Figure 1~~ Figure 1 below ((OUTSTANDING UPDATE OF FIGURE 1 FOR FINAL PUBLICATION OF VM0042 v2.0)):

Verified Carbon Standard

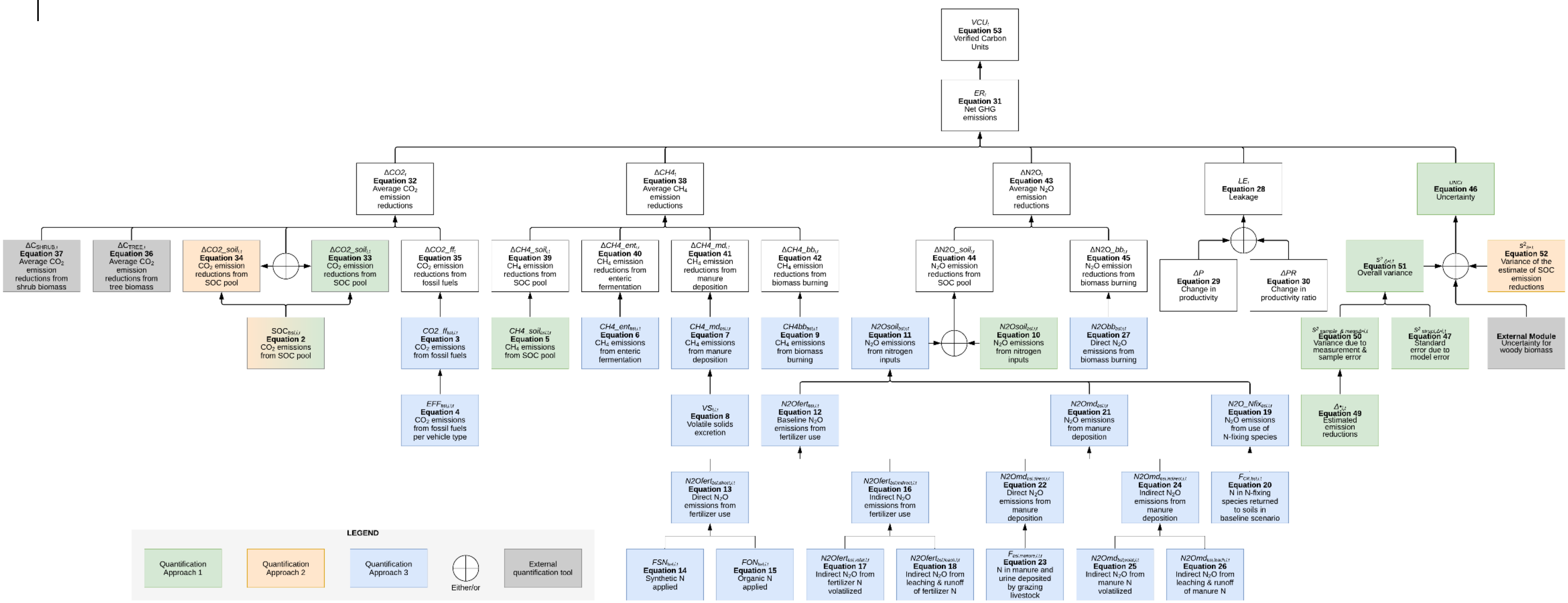

Figure 1: Equation map of the Methodology for Improved Agricultural Land Management

8.2.1 Soil Organic Carbon Stocks

Quantification Approach 1

Soil organic carbon stocks are estimated under Quantification Approach 1, using Equation 2 below:

Equation 2

$$SOC_{bsl,i,t} = f(SOC_{,bsl,i,t-1})$$

Where:

$SOC_{bsl,i,t}$	Estimated c~~C~~arbon stocks in the soil organic carbon pool in the baseline scenario for sample unit *i* at the end of period *t;* tCO_2e/unit area
$f(SOC_{,bsl,i,t-1})$	Modeled soil organic carbon stocks in the baseline scenario for sample unit *i* at the end of period *t-1*; tCO_2e/unit area
i	Sample unit

Quantification Approach 2

Changes in SOC stocks must be monitored in the baseline control sites. To ensure that changes in SOC stocks do not solely arise from a temporal change in bulk density (related to management practices), SOC stock changes should be calculated on an equivalent soil mass (ESM) basis[22]. Procedures to calculate SOC stock changes on an ESM basis should be based on (Ellert and Bettany, 1995; Wendt and Hauser, 2013; von Haden, Yang and DeLucia, 2020).

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

Equation 3

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

Where:

[22] Note that calibration and validation datasets used for modeling under Quantification Approach 1 do not need to meet the ESM requirement.

$M_{n,dl,SOC}$ SOC mass in one soil sample depth layer; kg/ha

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

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

N Number of cores sampled

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

The cumulative SOC mass per unit area are then calculated by addition of all sampled depth increments, at least down to 30 cm depth. Baseline SOC stocks must be reported for the baseline control sites and for each stratum within the project area, whenever stratification is applied as a sampling strategy (see section 9.3.1).

8.2.2 Change in Carbon Stocks in Aboveground and Belowground Woody Biomass

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

8.2.3 Carbon Dioxide Emissions from Fossil Fuel Combustion

If carbon dioxide emissions from fossil fuel are included in the project boundary per Table 3, they are quantified in the baseline scenario under Quantification Approach 3, using Equation 4 and Equation 5 below.

Parameter $CO2\_ff_{bsl,i,t}$ is estimated using the following equation:

Equation 4

$$CO2ff_{bsl,i,t} = (\sum_{j=1}^{J} EFF_{bsl,j,i,t})/A_i$$

Where:

$CO2\_ff_{bsl,i,t}$ Carbon dioxide emissions from fossil fuel combustion in the baseline scenario for sample unit *i* in year *t*; tCO_2e/unit area

$EFF_{bsl,j,i,t}$	Carbon dioxide emissions from fossil fuel combustion in the baseline scenario in fossil fuel vehicle/equipment type *j* for sample unit *i* in year *t;* tCO_2e
A_i	Area of sample unit *i*; unit area
j	Type of fossil fuel (gasoline or diesel)
i	Sample unit

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

Equation 5

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

Where:

$EFF_{bsl,j,i,t}$	Carbon dioxide emissions from fossil fuel combustion in the baseline scenario in vehicle/equipment type *j* for sample unit *i* in year *t*; tCO_2e
$FFC_{bsl,j,i,t}$	Consumption of fossil fuel type *j* for sample unit *i* in year *t*; liters
$EF_{CO2,j}$	Emission factor for the type of fossil fuel *j* combusted; tCO_2e/liter
j	Type of fossil fuel (gasoline or diesel)
i	Sample unit

8.2.4 Methane Emissions from the Soil Organic Carbon Pool

If methane emissions from ~~the~~ soil ~~organic pool~~ methanogenesis are included in the project boundary per Table 3, they are quantified in the baseline scenario under Quantification Approach 1 using Equation 6.

Equation 6

$$CH4soil_{bsl,i,t} = GWP_{CH4} \times ʃCH4soil_{bsl,i,t}$$

Where:

$CH4soil_{bsl,i,t}$	Methane emissions from soil organic carbon pool in the baseline scenario for sample unit *i* in year *t*; tCO_2e/unit area
$ʃCH4soil_{bsl,i,t}$	Modeled methane emissions from the soil organic carbon pool in the baseline scenario for sample unit *i* in year *t*; tCH_4e/unit area
GWP_{CH4}	Global warming potential for CH_4

i Sample unit

8.2.5 Methane Emissions from Livestock Enteric Fermentation

If methane emissions from livestock enteric fermentation are included per Table 3, they are quantified in the baseline scenario under Quantification Approach 3 using Equation 7.

Equation 7

$$CH4ent_{bsl,i,t} = \left(\frac{GWP_{CH4} * \sum_{l=1}^{L} P_{bsl,l,i,t} * Days_{bsl,l,i,t} * EF_{ent,l}}{1000 * 365}\right) / A_i$$

Where:

$CH4\_ent_{bsl,i,t}$	Methane emissions from livestock enteric fermentation in the baseline scenario for sample unit *i* in year *t*; tCO_2e/unit area
$P_{bsl,l,i,,t}$	Population of grazing livestock in the baseline scenario of type *l* in sample unit *i* in year *t;* head
$Days_{bsl,l,i,t}$	Average grazing days per head in the baseline scenario for each livestock type *l* in sample unit *i* in year *t;* days
$EF_{ent,l}$	Enteric emission factor for livestock type *l*; kg CH_4/(head * year)
GWP_{CH4}	Global warming potential for CH_4
A_i	Area of sample unit *i*; unit area
l	Type of livestock
i	Sample unit
365	days per year
1000	kg per tonne

8.2.6 Methane Emissions from Manure Deposition

If methane emissions from manure deposition are included in the project boundary per Table 3, they are quantified in the baseline scenario under Quantification Approach 3 using Equation 8 and Equation 9.

Equation 8

$$CH4_{md\,bsl,i,t} = \frac{GWP_{CH4} * \sum_{l=1}^{L}(P_{bsl,l,i,t} * VS_{l,i,t} * Days_{bsl,l,i,t} * EF_{CH4,md,l})}{10^6 * A_i}$$

Where:

$CH4\_md_{bsl,i,t}$	Baseline CH_4 emissions from manure deposition in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
GWP_{CH4}	Global warming potential for CH_4
$P_{bsl,l,i,,t}$	Population of grazing livestock in the baseline scenario of type *l* for sample unit *i* in year *t*; head
$VS_{l,i,t}$	Average volatile solids excretion per head for livestock type *l* in sample unit *i* in year *t*; kg volatile solids/(head * day)
$Days_{bsl,l,i,t}$	Average grazing days per head in the baseline scenario for each livestock type *l* in sample unit *i* in year *t;* days
$EF_{CH4,md,l}$	Emission factor for methane emissions from manure deposition for livestock type *l*; g CH4/(kg volatile solids)
A_i	Area of sample unit *i*; unit area
l	Type of livestock
i	Sample unit
10^6	Grams per tonne

Equation 9

$$VS_{l,i,t} = VS_{rate,l} * \frac{W_{bsl,l,i,t}}{1000}$$

Where:

$VS_{l,i,t}$	Annual volatile solids excretion of livestock type *l* for sample unit *i* in year *t*; kg volatile solids/(head * day)
$VS_{rate,l}$	Default volatile solids excretion rate for livestock type *l*; kg volatile solids/(1000 kg animal mass * day)
$W_{bsl,l,i,t}$	Average weight in the baseline scenario of livestock type *l* for sample unit *i* in year *t*; kg animal mass/head
1000	Kg per 1000 kg
l	Type of livestock
i	Sample unit

8.2.7 Methane Emissions from Biomass Burning

If methane emissions from biomass burning are included in the project boundary per Table 3, they are quantified in the baseline scenario under Quantification Approach 3 using Equation 10.

Equation 10

$$CH4bb_{bsl,i,t} = (\frac{GWP_{CH4} * \sum_{c=1}^{C} MB_{bsl,c,i,t} * CF_c * EF_{c,CH4}}{10^6})/A_i$$

Where:

$CH4\_bb_{bsl,i,t}$	Methane emissions in the baseline scenario from biomass burning for sample unit *i* in year *t*; t CO_2e/unit area
$MB_{bsl,c,i,t}$	Mass of agricultural residues of type *c* burned in the baseline scenario for sample unit *i* in year *t*; kilograms
CF_c	Combustion factor for agricultural residue type *c;* proportion of pre-fire fuel biomass consumed
$EF_{c,CH4}$	Methane emission factor for the burning of agricultural residue type *c*; g CH_4/kg dry matter burnt
GWP_{CH4}	Global warming potential for CH_4
A_i	Area of sample unit *i*; unit area
c	Type of agricultural residue
i	Sample unit
10^6	Grams per tonne

8.2.8 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. If 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, they are quantified in the baseline scenario under Quantification Approach 1 or Quantification Approach 3. If quantified under Quantification Approach 1, Equation 10 is used. If quantified under Quantification Approach 3, Equation 11 is used.

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:

Equation 11

$$N2Osoil_{bsl,i,t} = GWP_{N2O} \times fN2Osoil_{bsl,i,t}$$

Where:

$N2Osoil_{bsl,i,t}$	Direct and indirect nitrous oxide emissions due to nitrogen inputs to soils in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$fN2Osoil_{bsl,i,t}$	Modeled nitrous oxide emissions from soil (summed across the reporting period for sample unit *i*); t N_2O/unit area
GWP_{N2O}	Global warming potential for N_2O
i	Sample unit

Quantification Approach 3

Nitrous oxide emissions due to nitrogen inputs to soils in the baseline scenario estimated applying Equation 12.

Equation 12

$$N2Osoil_{bsl,i,t} = N2Ofert_{bsl,i.t} + N2Omd_{bsl,i,t} + N2ONfix_{bsl,i,t}$$

Where:

$N2Osoil_{bsl,i,t}$	Nitrous oxide emissions due to nitrogen inputs to soils in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$N2Ofert_{bsl,i,t}$	Nitrous oxide emissions due to fertilizer use in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$N2Omd_{bsl,i,t}$	Nitrous oxide emissions due to manure deposition in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$N2ONfix_{bsl,i,t}$	N_2O emissions due to the use of N-fixing species in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
i	Sample unit

Under Quantification Approach 3, if nitrous oxide emissions due to fertilizer use are included in the project boundary per Table 3, they are quantified in the baseline scenario using Equation 13, Equation 14, Equation 15, Equation 16, Equation 17, Equation 18 and Equation 19.

Equation 13

$$N2Ofert_{bsl,i,t} = N2Ofert_{bsl,direct,i,t} + N2Ofert_{bsl,indirect,i,t}$$

Where:

$N2Ofert_{bsl,i,t}$	Nitrous oxide emissions due to fertilizer use in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$N2Ofert_{bsl,direct,i,t}$	Direct nitrous oxide emissions due to fertilizer use in the baseline scenario for sample unit *i* in year *t;* t CO_2e/unit area
$N2Ofert_{bsl,indirect,i,t}$	Indirect nitrous oxide emissions due to fertilizer use in the baseline scenario for sample unit *i* in year *t;* t CO_2e/unit area
i	Sample unit

Under Quantification Approach 3, direct nitrous oxide emissions due to fertilizer use in the baseline scenario are quantified in Equation 14, Equation 15 and Equation 16.

Equation 14

$$N2Ofert_{bsl,direct,i,t} = ((FSN_{bsl,i,t} + FON_{bsl,i,t}) \times EF_{Ndirect} \times 44/28 \times GWP_{N2O})/A_i$$

Equation 15

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

Equation 16

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

Where:

$N2Ofert_{bsl,direct,i,t}$	Direct nitrous oxide emissions due to fertilizer use in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$FSN_{,bsl,i,t}$	Baseline synthetic N fertilizer applied for sample unit *i* in year *t*; t N

$FON_{,bsl,i,t}$	Baseline organic N fertilizer applied for sample unit *i* in year *t*; t N
$M_{bsl,SF,i,t}$	Mass of baseline N containing synthetic fertilizer type *SF* applied for sample unit *i* in year *t;* t fertilizer
$M_{bsl,OF,i,t}$	Mass of baseline N containing organic fertilizer type *OF* applied for sample unit *i* in year *t*; t fertilizer
$NC_{bsl,SF}$	N content of baseline synthetic fertilizer type *SF* applied; t N/t fertilizer
$NC_{bsl,OF}$	N content of baseline organic fertilizer type *OF* applied; t N/t fertilizer
$EF_{Ndirect}$	Emission factor for nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments and crop residues; t N2O-N/t N applied
SF	Synthetic N fertilizer type
OF	Organic N fertilizer type
A_i	Area of sample unit *i*; unit area
GWP_{N2O}	Global warming potential for N_2O
i	Sample unit
$44/28$	Ratio of molecular weight of N_2O to molecular weight of N applied to convert N_2O-N emissions to N_2O emissions

Under Quantification Approach 3, indirect nitrous oxide emissions due to fertilizer use in the baseline scenario are quantified in Equation 17, Equation 18 and Equation 19.

Equation 17

$$N2Ofert_{bsl,indirect,i,t} = (N2Ofert_{bsl,volat,i,t} + N2Ofert_{bsl,leach,i,t})/A_i$$

Equation 18

$$N2Ofert_{bsl,volat,i,t} = [(FSN_{bsl,i,t} \times Frac_{GASF}) + (FON_{bsl,i,t} \times Frac_{GASM})] \times EF_{Nvolat} \times 44/28 \times GWP_{N2O}$$

Equation 19

$$N2Ofert_{bsl,leach,i,t} = (FSN_{bsl,i,t} + F_{ONbsl,i,t}) \times Frac_{LEACH} \times EF_{Nleach} \times 44/28 \times GWP_{N2O}$$

Where:

$N2O\_fert_{bsl,indirect,i,t}$	Indirect nitrous oxide emissions due to fertilizer use in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$N2O\_fert_{bsl,volat,i,t}$	Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to fertilizer use for sample 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 for sample unit *i* in year *t*; t CO_2e.
$FSN_{bsl,i,t}$	Baseline synthetic N fertilizer applied for sample unit *i* in year *t*; t N
$FON_{bsl,i,t}$	Baseline organic N fertilizer applied for sample unit *i* in year *t*; t N
$Frac_{GASF}$	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
Frac_{LEACH}	Fraction of N added (synthetic or organic) to soils and in manure and urine deposited on soils that is lost through leaching and runoff, in regions where leaching and runoff occurs; dimensionless. For wet climates[23] or in dry climate regions where irrigation (other than drip irrigation) is used, a value of 0.24 is applied. For dry climates, a value of zero is applied.
EF_{Nvolat}	Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces; t N2O-N /(t NH3-N + NOx-N volatilized)
EF_{Nleach}	Emission factor for nitrous oxide emissions from leaching and runoff; t N2O-N / t N leached and runoff
A_i	Area of sample unit *i*; unit area
GWP_{N2O}	Global warming potential for N_2O
i	Sample unit
$44/28$	Ratio of molecular weight of N_2O to molecular weight of N applied to convert N_2O-N emissions to N_2O emissions

If nitrous oxide emissions due to the use of N-fixing species are included in the project boundary per Table 3, they are quantified in the baseline scenario under Quantification Approach 3 using Equation 20 and Equation 21.

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

Equation 20

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

Where:

$N2O\_Nfix_{bsl,i,t}$	Nitrous oxide emissions due to the use of N-fixing species in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$F_{CR,bsl,,i,t}$	Amount of N in N-fixing species (above and below ground) returned to soils in the baseline scenario for sample unit *i* in year *t*; t N
$EF_{Ndirect}$	Emission factor for nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments and crop residues; t N2O-N/t N applied
A_i	Area of sample unit *i*; unit area
GWP_{N2O}	Global warming potential for N_2O
i	Sample unit
$44/28$	Ratio of molecular weight of N_2O to molecular weight of N applied to convert N_2O-N emissions to N_2O emissions

Equation 21

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

Where:

$F_{CR,bsl,,i,t}$	Amount of N in N-fixing species (above and below ground) returned to soils in the baseline scenario in sample unit *i* in year *t*; t N
$MB_{g,bsl,i,t}$	Annual dry matter, including aboveground and below ground, of N-fixing species *g* returned to soils for sample unit *i* in year *t*; t dm
$N_{content,g}$	Fraction of N in dry matter for N-fixing species *g*; t N/t dm
g	Type of N-fixing species
i	Sample unit

8.2.9 Nitrous Oxide Emissions from Manure Deposition

If nitrous oxide emissions due to manure deposition are included in the project boundary per

Table 3, they are quantified in the baseline scenario under Quantification Approach 3 using Equation 22, Equation 23, Equation 24, Equation 25, Equation 26 and Equation 27.

Equation 22

$$N2Omd_{bsl,i,t} = N2Omd_{bsl,direct,i,t} + N2Omd_{bsl,indirect,i,t}$$

Where:

$N2O\_md_{bsl,i,t}$	Nitrous oxide emissions due to manure deposition in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$N2O\_md_{bsl,direct,i,t}$	Direct nitrous oxide emissions due to manure deposition in the baseline scenario for sample unit *i* in year *t;* t CO_2e/unit area
$N2O\_md_{bsl,indirect,i,t}$	Indirect nitrous oxide emissions due to manure deposition in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
i	Sample unit

Direct nitrous oxide emissions due to manure deposition in the baseline scenario are quantified using Equation 23 and Equation 24.

Equation 23

$$N2Omd_{bsl,direct,i,t} = (\sum_{l=1}^{L} F_{bsl,manure,l,i,t} \times EF_{N2O,md,l} \times 44/28 \times GWP_{N2O})/A_i$$

Equation 24

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

Where:

$N2O\_md_{bsl,direct,i,t}$	Direct nitrous oxide emissions due to manure deposition in the baseline scenario for sample unit *i* in year *t;* t CO_2e/unit area
$F_{bsl,manure,l,i,t}$	Amount of nitrogen in manure and urine deposited on soils by livestock type *l* in sample unit *i* in year *t*; t N
$P_{bsl,l,i,t}$	Baseline population of livestock type *l* for sample unit *i* in year *t*; head
Nex_l	Average annual nitrogen excretion per head of livestock type *l*; kg N/head/year
$EF_{N2O,md,l}$	Emission factor for nitrous oxide from manure and urine deposited on soils by livestock type *l*; kg N_2O-N/kg N input

GWP_{N2O}	Global warming potential for N_2O
$MS_{bsl,l,I,t}$	Baseline fraction of total annual N excretion for each livestock type *l* for sample unit *i* in year *t* that is deposited on the project area; %
A_i	Area of sample unit *i*; unit area
l	Type of livestock
i	Sample unit
$44/28$	Ratio of molecular weight of N_2O to molecular weight of N applied to convert N_2O-N emissions to N_2O emissions

Indirect nitrous oxide emissions due to manure deposition in the baseline scenario are quantified under Quantification Approach 3 using Equation 25, Equation 26 and Equation 27.

Equation 25

$$N2Omd_{bsl,indirect,i,t} = (N2O_m d_{bsl,volat,i,t} + N2O_m d_{bsl,leach,i,t})/A_i$$

Equation 26

$$N2Omd_{bsl,volat,i,t} = F_{bsl,manure,l,i,t} \times Frac_{GASM} \times EF_{Nvolat} \times \frac{44}{28} \times GWP_{N2O}$$

Equation 27

$$N2Omd_{bsl,leach,i,t} = F_{bsl,manure,l,i,t} \times Frac_{LEACH} \times EF_{Nleach} \times \frac{44}{28} \times GWP_{N2O}$$

Where:

$N2O\_md_{bsl,indirect,i,t}$	Indirect nitrous oxide emissions due to manure deposition in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$N2O\_md_{bsl,volat,i,t}$	Indirect nitrous oxide emissions produced from atmospheric deposition of N volatilized due to manure deposition for sample 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 sample unit *i* in year *t.* Equal to 0 where annual precipitation is less than potential evapotranspiration, unless irrigation is employed; t CO_2e
$F_{bsl,manure,l,i,t}$	Amount of nitrogen in manure and urine deposited on soils by livestock type *l* in sample unit *i* in year *t*; t N/unit area

$Frac_{GASM}$	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 N2O-N /(t NH3-N + NOx-N volatilized
Frac_{LEACH}	Fraction of all organic N added to soils and N in manure and urine deposited on soils that is lost through leaching and runoff, in regions where leaching and runoff occurs; dimensionless. For wet climates[24] or in dry climate regions where irrigation (other than drip irrigation) is used, a value of 0.24 is applied. For dry climates, a value of zero is applied.
EF_{Nleach}	Emission factor for nitrous oxide emissions from leaching and runoff; t N2O-N / t N leached and runoff
A_i	Area of sample unit *i*; unit area
GWP_{N2O}	Global warming potential for N_2O
l	Type of livestock
i	Sample unit

8.2.10 Nitrous Oxide Emissions from Biomass Burning

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

Parameter $N2O\_bb_{bsl,i,t}$ is estimated using Equation 28.

Equation 28

$$N2Obb_{bsl,i,t} = \left(\frac{GWP_{N2O} \times \sum_{c=1}^{C} MB_{bsl,c,i,t} \times CF_c \times EF_{c,N2O}}{10^6}\right)/A_i$$

Where:

$N2O\_bb_{bsl,i,t}$	Nitrous oxide emissions in the baseline scenario from biomass burning for sample unit *i* in year *t*; t CO_2e/unit area

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

$MB_{bsl,c,i,t}$	Mass of agricultural residues of type *c* burned in the baseline scenario for sample unit *i* in year *t*; kilograms
CF_c	Combustion factor for agricultural residue type *c*; proportion of pre-fire fuel biomass consumed
$EF_{c,N2O}$	Nitrous oxide emission factor for the burning of agricultural residue type c; g N_2O/kg dry matter burnt
A_i	Area of sample unit *i*; unit area
GWP_{N2O}	Global warming potential for N_2O
i	Sample unit
10^6	Grams per tonne

8.3 Project Emissions

Stock change/emissions resulting from agricultural management activities taking place in the project scenario are either calculated or modeled on the basis of monitored inputs. The estimation of emissions of CO_2, CH_4, and N_2O in the project scenario from included sources must follow approaches provided in Table 5 and using the same equations in Section 8.2~~8.1.8.1.~~ For all equations, the subscript *bsl* must be substituted by *wp* to make clear that the relevant values are being quantified for the project scenario. Further, as per Section 8.4.2 ~~8.4.1,8.4.1,~~ if livestock is~~are~~ included in the baseline, the minimum value allowed for the project is equal to the average value from the historical baseline period.

Quantification Approach 1

Model inputs must be collected following guidance in Table 8.~~Table 7.~~

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

Model Input Category	Timing	Approach
Soil organic carbon ~~stock~~ content and bulk density to calculate SOC stocks	Determined at project start (re-measured every 5 years or less)	Directly measured via conventional analytical laboratory methods, e.g., dry combustion, ~~-~~or estimated via emerging technologies (INS, LIBS, MIR and Vis-NIR~~e.g., remote sensing~~) with known uncertainty following the criteria in ~~Appendix 4~~Appendix 4, every 5 years or less. See parameter table for $SOC_{wp,i,t}$.
Soil properties (other than bulk	Determined *ex ante*	Measured or determined from published soil maps with known uncertainty.

density and soil organic carbon)		Estimates from direct measurements must: • Derived from representative (unbiased) sampling • Accuracy of measurements is ensured through adherence to best practices (to be determined by the project proponent and outlined in the monitoring plan)
Climate variables (e.g., precipitation, temperature)	Continuously monitored *ex post*	Measured for each model-specific meteorological input variable at its required temporal frequency (e.g., daily) model prediction interval. Measurements are taken at the closest continuously-monitored weather station, not exceeding 50 km of the sample field, or from a synthetic weather station (e.g., PRISM[25]).
Agricultural management activities (as identified following procedures in VMD0053 "Model Calibration and Validation Guidance for the Methodology for Improved Agricultural Land Management", referencing categories of practices outlined in applicability condition 1)	Monitored *ex post*	Required model inputs related to agricultural management practices will be monitored and recorded for each project year, *t*. Information on agricultural management practices will be monitored via consultation with, and substantiated with a signed attestation from, the farmer or landowner of the sample unit. Any quantitative information (e.g., discrete or continuous numeric variables) on agricultural management practices must be supported by one or more forms of documented evidence pertaining to the selected sample field and relevant monitoring period (e.g., management logs, receipts or invoices, farm equipment specifications).

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

		Units for quantitative information will be based on model input requirements.

Quantification Approach 2

Quantification Approach 2 is applied for the estimation of emissions from soil organic carbon stocks only. Soil organic carbon stocks in the project scenario (*$SOC_{wp,i,t}$*) are calculated on an equivalent soil mass (ESM) basis by multiplication with the *soil organic carbon content* ~~as~~ in each sample unit or stratum at time *t-1* directly measured in each sample field. When bulk density is measured in a fixed depth approach, mass corrections can be applied to meet the ESM requirement.

A detailed description of SOC stock calculations with multiple soil depth increments along with spreadsheets ~~or~~and R scripts to standardize and facilitate calculations on an ESM basis are provided in (Wendt and Hauser, 2013) and (von Haden, Yang and DeLucia, 2020). SOC stock changes are calculated in equation 33.

~~*Note – Currently Quantification Approach 2 cannot be used because a performance benchmark does not exist.*~~

Quantification Approach 3

Project emissions are calculated for each sample field using applicable default values and any monitored parameters.

Woody Biomass

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

8.4 Leakage

Improved ALM projects can result in leakage through new application of manure from outside the project area (i.e., manure applied in the project from outside of the project area, that was not previously applied in the historical baseline period), productivity declines, and/or the displacement of livestock outside of the project boundary. Guidance on how to account for each of these types of leakage is provided below.

8.4.1 Accounting for Leakage from New[26] Application of ~~Manure~~ Organic Amendments from Outside the Project Area

If new[27] manure, compost or biosolids ~~is~~ are applied in the project that ~~was~~ were not applied in the historical baseline period, there is a risk of activity shifting leakage. To account for this type of leakage, a deduction must be applied unless:

1. The manure or compost applied in the project is produced on-site from farms within the project area;
2. The manure ~~can be~~is documented to have been diverted from an uncontrolled anaerobic lagoon, pond, tank or pit;[28] from which there is no recovery of methane for generation of heat and/or electricity~~, nor use as soil amendment~~; or;[29] ~~or~~
3. The manure, compost or biosolids is documented to not have been used as a soil amendment.

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

Equation 29 estimates the SOC increase from imported manure, compost or biosolids application activities, reducing the total amount of carbon applied to 12% per a global manure-C retention coefficient sourced from Maillard and Angers (2014). ~~(Maillard and Angers, (2014) Maillard and Angers (2014).~~ While derived for manure, the equation is conservatively applied to compost or biosolids for the purposes of this methodology.

Equation 29

$$LE_t = \sum_l \left(M\_manure_{prj,l,t} \times CC_{prj,l,t} \times 0.12 \times \frac{44}{12} \right)$$

Where:

LE_t Leakage in year t; t CO_2e

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

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

$M\_manure_{prj,l,t}$	Mass of manure applied as fertilizer on the project area from livestock type *l* in year *t*; tonnes
$CC_{prj,l,t}$	Carbon content of manure applied as fertilizer on the project area from livestock type l in year *t*; fraction
0.12	Fraction of manure carbon expected to remain in the soils on the project area by the end of the project term ; fraction
$\frac{44}{12}$	Conversion from carbon to carbon dioxide equivalent; t C/t CO_2e

8.4.2 Accounting for Leakage from Livestock Displacement

To avoid crediting emission reductions 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), the number of livestock in the project scenario must not be lower than the number of livestock in the historical baseline period. Thus, if livestock displacement occurs, the CH_4 and N_2O emissions associated with livestock must continue to be counted in the project scenario (in sections 8.2.6 ~~Equation 7~~and 8.2.9) to account for potential emissions leakage.

8.4.3 Accounting for Leakage from Productivity Declines

Market leakage is likely to be negligible because the land in the project scenario remains in agricultural production. Further, producers are unlikely to implement and maintain management practices that result in productivity declines, since their livelihoods depend on crop harvests as a source of income. Nevertheless, to ensure leakage is not occurring, the following steps must be completed every 10 years:

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

1. Average with-project productivity (excluding years with extreme[30] weather events) of each crop/livestock product to average pre-project productivity of the same crop/livestock product using Equation 30.

Equation 30

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

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

Where:

ΔP	Change in productivity; percent
$P_{wp,p}$	Average productivity for product p during the project period; productivity per hectare or acre
$P_{bsl,p}$	Average productivity for product p during the historical baseline period; productivity per hectare or acre
p	crop/livestock product

Or

2. The ratio of average baseline productivity to regional productivity at time t to the average ratio of project productivity to regional productivity at time t + 10 years, by crop/livestock product, using Equation 31 and regional data from government (e.g., USDA Actual Production History (APH) data), industry, published, academic or international organization (e.g., FAO) sources.[31]

Equation 31

$$\Delta PR = \left(\frac{P_{wp,p}}{RP_{wp,p}} - \frac{P_{bsl,p}}{RP_{bsl,p}}\right) \times 100$$

Where:

ΔPR	Change in productivity ratio per hectare or acre
$P_{wp,p}$	Average productivity for product p during the project period
$P_{bsl,p}$	Average productivity for product p during the historical baseline period
$RP_{wp,p}$	Average regional productivity for product p during the same years as the project period
$RP_{bsl,p}$	Average regional productivity product p during the same years as the historical baseline period
p	crop/livestock product

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

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

Step 2: Determine whether the crop/livestock productivity decline was caused by a short-term change in productivity, by repeating the calculation in step 1 excluding all data inputs from the first three years of project implementation on a farm. If the with-project productivity of the crop/livestock product with the first three years removed is within 5% of the baseline productivity of the same crop/livestock product, no further action is needed[32]. If a reduction in productivity of greater than 5% is still observed in one or more crop/livestock product(s), complete step 3 for these products.

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

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

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

8.5 Gross and Net GHG Emission Reductions and Removals

Gross GHG emission reductions and removals are quantified as:

Equation 32

$$ERR_{g,t} = E_{red,g,t} + E_{rem,g,t}$$

Where:

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

$ERR_{g,t}$ Estimated gross GHG emission reductions and removals in year t; t CO_2e

$E_{red,g,t}$ Estimated gross GHG emission reductions in year t; t CO_2e

$E_{rem,g,t}$ Estimated gross GHG emission removals in year t; t CO_2e

Gross GHG emission reductions are quantified as:

Equation 33

$$E_{red,g,t} = \overline{\Delta CO2\_ff_t} + \overline{\Delta CH4\_ent_t} + \overline{\Delta CH4\_md_t} + \overline{\Delta CH4\_bb_t} + \overline{\Delta CH4\_soil_t} + \overline{\Delta N2O\_soil_t} + \overline{\Delta N2O\_bb_t}$$

Where:

$E_{red,g,t}$ Estimated gross GHG emissions reductions in year t; t CO_2e

$\overline{\Delta CO2\_ff_t}$ Areal average carbon dioxide emission reductions from fossil fuel combustion in year t; t CO_2-e/unit area

$\overline{\Delta CH4\_ent_t}$ Areal average methane emission reductions from livestock enteric fermentation in year t; t CO_2e/unit area

$\overline{\Delta CH4\_md_t}$ Areal average methane emission reductions from manure deposition in year t; t CO_2e/unit area

$\overline{\Delta CH4\_bb_t}$ Areal average methane emission reductions from avoided or reduced biomass burning in year t; t CO_2e/unit area

$\overline{\Delta CH4\_soil_t}$ Areal average methane emission reductions from increasing uptake into the soil organic carbon pool in year t; t CO_2e/unit area

$\overline{\Delta N2O\_soil_t}$ Areal average nitrous oxide emission reductions from nitrification/denitrification in year t; t CO_2e/unit area

$\overline{\Delta N2O\_bb_t}$ Areal average nitrous oxide emission reductions from avoided or reduced biomass burning in year t; t CO_2e/unit area

Gross GHG emissions removals are quantified as:

Equation 34

$$E_{rem,g,t} = \overline{\Delta CO2\_soil_t} + \overline{\Delta C_{TREE,t}} + \overline{\Delta C_{SHRUB,t}}$$

Where:

$E_{rem,g,t}$ Estimated gross GHG emissions removals in year t; t CO_2e

$\overline{\Delta CO2\_soil_t}$ Areal average carbon dioxide emission removals ~~by enhancing~~from increasing the soil organic carbon pool in year t; t CO_2e/unit area

$\overline{\Delta C_{TREE,t}}$ Areal average carbon dioxide emission removals from increasing ~~by enhancing~~ tree biomass in year t; t CO_2-e/unit area

$\overline{\Delta C_{SHRUB,t}}$ Areal average carbon dioxide emission removals from increasing ~~by enhancing~~ shrub biomass in year *t*; t CO_2-e/unit area

Net GHG emission reductions and removals are quantified as:

Equation 35

$$ERR_{n,t} = E_{red,n,t} + E_{rem,n,t}$$

Where:

$\boldsymbol{ERR_{n,t}}$ Estimated net GHG emission reductions and removals in year *t*; t CO_2e

$\boldsymbol{E_{red,n,t}}$ Estimated net GHG emission reductions in year t; t CO_2e

$\boldsymbol{E_{rem,n,t}}$ Estimated net GHG emission removals in year t; t CO_2e

Net GHG emission reductions are quantified as:

Equation 36

$$E_{red,n,t} = \left(\left(A_0 \times \frac{E_{red,g,t}}{ERR_{g,t}}\right) \times E_{red,g,t} - \left(LE_t \times \frac{E_{red,g,t}}{ERR_{g,t}}\right)\right) \times \left(1 - \left(UNC_t \times \frac{E_{red,g,t}}{ERR_{g,t}}\right)\right)$$

Where:

$E_{red,n,t}$ Estimated net GHG emission reductions in year t; t CO_2e

A_0 Project area; unit area

$E_{red,g,t}$ Estimated gross GHG emission reductions in year *t*; t CO_2e

$ERR_{g,t}$ Estimated gross GHG emission reductions and removals in year *t*; t CO_2e

LE_t Leakage in year *t*, equal to zero; t CO_2e

UNC_t Uncertainty deduction in year t; fraction between 0 and 1

Net GHG emission removals are quantified as:

Equation 37

$$E_{rem,n,t} = \left(\left(A_0 \times \frac{E_{rem,g,t}}{ERR_{g,t}}\right) \times E_{rem,g,t} - \left(LE_t \times \frac{E_{rem,g,t}}{ERR_{g,t}}\right)\right) \times \left(1 - \left(UNC_t \times \frac{E_{rem,g,t}}{ERR_{g,t}}\right)\right)$$

Where:

$E_{rem,n,t}$ Estimated net GHG emission removals in year t; t CO_2e

A_0 Project area; unit area

$E_{rem,g,t}$ Estimated gross GHG emission removals in year *t*; t CO_2e

$ERR_{g,t}$	Estimated gross GHG emission reductions and removals in year *t*; t CO_2e
LE_t	Leakage in year *t*, equal to zero; t CO_2e
UNC_t	Uncertainty deduction in year t; fraction between 0 and 1

~~8.4.4~~8.5.1 Carbon dioxide emission reductions and removals

See parameter tables in Section 9.2 for derivation of $\Delta_{\bullet,t}\bar{\Delta}_{\bullet,t}$ and $\bullet_t\bar{\bullet}_t$

Carbon dioxide emission removals by enhancing~~reductions from~~ the soil organic carbon pool for sample unit *i* in year *t* are quantified for Quantification Approach 1 using Equation 38 or Equation 39.

Equation 38

$$\Delta CO2\_soil_{i,t} = \left(SOC_{wp,i,t} - SOC_{wp,i,t-1}\right) - \left(SOC_{bsl,i,t} - SOC_{bsl,i,t-1}\right)$$

Where:

$\Delta CO2\_soil_{i,t}$	Carbon dioxide emission removals by enhancing the~~reductions from~~ soil organic carbon pool for sample unit *i* in year *t*; t CO_2e /unit area
$SOC_{wp,i,t}$	Carbon stocks in the soil organic carbon pool in the project scenario for sample field *i* at the end of year *t*; t CO_2e /unit area
$SOC_{wp,i,t-1}$	Carbon stocks in the soil organic carbon pool in the project scenario for sample field *i* at the end of year *t-1*; t CO_2e /unit area
$SOC_{bsl,i,,t}$	Carbon stocks in the soil organic carbon pool in the baseline scenario for sample field *i* at the end of year *t*; t CO_2e/unit area
$SOC_{bsl,i,,t-1}$	Carbon stocks in the soil organic carbon pool in the baseline scenario for sample field *i* at the end of year *t-1*; t CO_2e/unit area
i	Sample unit

The initial SOC is the same in both the baseline and project scenarios at the outset of the project (i.e., $SOC_{wp,i,0} = SOC_{bsl,i,0}$); as a result, the first calculation of ~~Equation 33Equation 33~~ Equation 38 on sample unit *i* simplifies to $SOC_{wp,i,t} - SOC_{bsl,i,t}$.

For Quantification Approach 2, carbon dioxide emission removals by enhancing ~~reductions from~~ the soil organic carbon pool for sample unit *i* in year *t* are compared to a baseline stock change that is equal to the performance benchmark (where an applicable performance benchmark exists)[33] or to the estimated stock change in baseline control plots, using Equation 39.~~:~~

[33] Performance benchmarks for demonstration of the crediting baseline currently (as of the date of publication) do not exist. Such performance benchmarks may be established through a revision to this methodology following requirements in the most current versions of the ~~*VCS Standard* and~~ *VCS Methodology Requirements (see VCS Methodology Requirements v4.0, Sections 2.3 and 3.4.5).*

~~Equation 34~~Equation 39

$$\Delta CO2\_soil_{i,t} = (SOC_{wp,i,t} - SOC_{wp,i,t_{previous}}) - \left(SOC_{bsl,i,t} - SOC_{bsl,i,t_{previous}}\right)$$

Where:

$\Delta CO2\_soil_{i,t}$	Estimated carbon dioxide emission removals by enhancing the ~~reductions from~~ soil organic carbon pool for sample unit *i* at the end of year *t*; t CO_2e/unit area
$SOC_{wp,i,t}$	Estimated carbon stocks in the soil organic carbon pool in the project scenario for sample field *i* at the end of year *t*; t CO_2e/unit area
$SOC_{wp,i,t\_previous}$	Estimated carbon stocks in the soil organic carbon pool in the project scenario for sample field *i* at the previous measurement year, *t_previous*; t CO_2e/unit area
$SOC_{bsl,i,t}$	Estimated carbon stocks in the soil organic carbon pool in the baseline scenario for sample field *i* at the end of year *t*; t CO_2e/unit area
$SOC_{bsl,i,t\_previous}$	Estimated carbon stocks in the soil organic carbon pool in the baseline scenario for sample field *i* at the previous measurement year, *t_previous*; t CO_2e/unit area
i	Sample unit

Where the period between time *t* and time *t_previous* spans multiple calendar years, the project proponent shall pro-rate the results of Equation 39 ~~Equation 34~~across the relevant vintages according to the number of days in the monitoring period contained within each vintage. For example, if the total stock change is measured across exactly three calendar years, then one third of the stock change would be attributed to each vintage. As explained in section 8.2.1 and in parameter tables in Section 9.2, SOC stock changes must be calculated on an equivalent soil mass basis.

Carbon dioxide emission reductions from fossil fuel combustion are quantified as:

~~Equation 35~~Equation 40

$$\Delta CO2\_ff_{i,t} = CO2\_ff_{bsl,i,t} - CO2\_ff_{wp,i,t}$$

Where:

$\Delta CO2\_ff_{i,t}$	Carbon dioxide emission reductions from fossil fuel combustion for sample unit *i* in year *t*; t CO_2e/unit area
$CO2\_ff_{bsl,i,t}$	Carbon dioxide emissions from fossil fuel combustion in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$CO2\_ff_{wp,i,t}$	Carbon dioxide emissions from fossil fuel combustion in the project scenario for sample unit *i* in year *t*; t CO_2e/unit area

i Sample unit

Carbon dioxide emission removals in tree biomass are quantified as:

Equation 41

$$\overline{\Delta C_{TREE,t}} = \overline{\Delta C_{TREE,wp,t}} - \overline{\Delta C_{TREE,bsl,t}}$$

Where:

$\overline{\Delta C_{TREE,t}}$	Areal average carbon dioxide emission removals by enhancing~~reductions from~~ tree biomass in year *t*; t CO_2-e/unit area
$\overline{\Delta C_{TREE,wp,t}}$	Areal average baseline carbon stock change in tree biomass in year *t*; t CO_2-e/unit area
$\overline{\Delta C_{TREE,bsl,t}}$	Areal average project scenario carbon stock change tree biomass in year *t*; t CO_2-e/unit area

Carbon dioxide emission removals in shrub biomass are quantified as:

Equation 42

$$\overline{\Delta C_{SHRUB,t}} = \overline{\Delta C_{SHRUB,wp,t}} - \overline{\Delta C_{SHRUB,bsl,t}}$$

Where:

$\overline{\Delta C_{SHRUB,t}}$	Areal average carbon dioxide emission removals by enhancing~~reductions from~~ ~~tree~~ shrub biomass in year *t*; t CO_2-e/unit area
$\overline{\Delta C_{SHRUB,wp,t}}$	Areal average baseline carbon stock change in ~~tree~~ shrub biomass in year *t*; t CO_2-e/unit area
$\overline{\Delta C_{SHRUB,bsl,t}}$	Areal average project scenario carbon stock change ~~tree~~ shrub biomass in year *t*; t CO_2-e/unit area

~~8.4.5~~8.5.2 Methane emission reductions ($\overline{\Delta CH4_t}$)

See parameter tables in Section 9.2 for derivation of $\Delta_{\bullet,t}\overline{\Delta}_{\bullet,t}$ and $\bullet_t\overline{\bullet}_t$

Methane emission reductions are quantified as:

Equation 43

$$\overline{\Delta CH4_t} = \overline{\Delta CH4\_soil_t} + \overline{\Delta CH4\_ent_t} + \overline{\Delta CH4\_md_t} + \overline{\Delta CH4\_bb_t}$$

Where:

$\overline{\Delta CH4_t}$	Areal average methane emission reductions in year *t*; t CO_2e/unit area
$\overline{\Delta CH4\_soil_t}$	Areal average methane emission reductions from soil organic carbon pool in year *t*; t CO_2e/unit area
$\overline{\Delta CH4\_ent_t}$	Areal average methane emission reductions from livestock enteric fermentation in year *t*; t CO_2e/unit area
$\overline{\Delta CH4\_md_t}$	Areal average methane emission reductions from manure deposition in year *t*; t CO_2e/unit area
$\overline{\Delta CH4\_bb_t}$	Areal average methane emission reductions from avoided or reduced biomass burning in year *t*; t CO_2e/unit area

Methane emission reductions from the soil organic carbon pool are quantified as:

Equation 44

$$\Delta CH4\_soil_{i,t} = CH4\_soil_{bsl,i,t} - CH4\_soil_{wp,i,t}$$

Where:

$\Delta CH4\_soil_{i,t}$	Methane emission removals by increasing uptake into~~reductions from~~ soil organic carbon pool for sample unit *i* in year *t*; t CO_2e/unit area
$CH4\_soil_{bsl,i,t}$	Methane emissions from soil organic carbon pool in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$CH4\_soil_{wp,i,t}$	Methane emissions from soil organic carbon pool in the project scenario for sample unit *i* in year *t*; t CO_2e/unit area
i	Sample unit

Methane emission reductions from livestock enteric fermentation are quantified as:

Equation 45

$$\Delta CH4\_ent_{i,t} = CH4\_ent_{bsl,i,t} - CH4\_ent_{wp,i,t}$$

Where:

$\Delta CH4\_ent_{i,t}$	Methane emission reductions from livestock enteric fermentation for sample unit *i* in year *t*; t CO_2e/unit area

$CH4\_ent_{bsl,i,t}$	Methane emissions from livestock enteric fermentation in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$CH4\_ent_{wp,i,t}$	Methane emissions from livestock enteric fermentation in the project scenario for sample unit *i* in year *t*; t CO_2e/unit area
i	Sample unit

Methane emission reductions from manure deposition are quantified as:

Equation 46

$$\Delta CH4\_md_{i,t} = CH4\_md_{bsl,i,t} - CH4\_md_{wp,i,t}$$

Where:

$\Delta CH4\_md_{i,t}$	Methane emission reductions from manure deposition for sample unit *i* in year *t*; t CO_2e/unit area
$CH4\_md_{bsl,i,t}$	Methane emissions from manure deposition in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$CH4\_md_{wp,i,t}$	Methane emissions from manure deposition in the project scenario for sample unit *i* in year *t*; t CO_2e/unit area
i	Sample unit

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

Equation 47

$$\Delta CH4\_bb_{i,t} = CH4\_bb_{bsl,i,t} - CH4\_bb_{wp,i,t}$$

Where:

$\Delta CH4\_bb_{i,t}$	Methane emission reductions from avoided or reduced biomass burning for sample unit *i* in year *t*; t CO_2e/unit area
$CH4\_bb_{bsl,i,t}$	Methane emissions from biomass burning in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$CH4\_bb_{wp,i,t}$	Methane emissions from biomass burning in the project scenario for sample unit *i* in year *t;* t CO_2e/unit area
i	Sample unit

~~8.4.6~~8.5.3 Nitrous oxide emission reductions ($\overline{\Delta N2O_t}$)

See parameter tables in Section 9.2 for derivation of $\Delta_{\bullet,t}\overline{\Delta}_{\bullet,t}$ and $\bullet_t\overline{\bullet}_t$

Nitrous oxide emission reductions are quantified as:

Equation 48

$$\overline{\Delta N2O_t} = \overline{\Delta N2O\_soil_t} + \overline{\Delta N2O\_bb_t}$$

Where:

$\overline{\Delta N2O_t}$	Areal average nitrous oxide emission reductions in year *t*; t CO_2e/unit area
$\overline{\Delta N2O\_soil_t}$	Areal average nitrous oxide emission reductions from nitrification/denitrification in year *t*; t CO_2e/unit area
$\overline{\Delta N2O\_bb_t}$	Areal average nitrous oxide emission reductions from avoided or reduced biomass burning in year *t*; t CO_2e/unit area

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

Equation 49

$$\Delta N2O\_soil_{i,t} = N2O\_soil_{bsl,i,t} - N2O_{soil_{wp,i,t}}$$

Where:

$\Delta N2O\_soil_{i,t}$	Nitrous oxide emission reductions from nitrification/denitrification for sample unit *i* in year *t*; t CO_2e/unit area
$N2O\_soil_{bsl,i,t}$	Nitrous oxide emissions from nitrogen inputs to soils in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$N2O\_soil_{wp,i,t}$	Nitrous oxide emissions from nitrogen inputs to soils in the project scenario for sample unit *i* in year *t*; t CO_2e/unit area
i	Sample unit

Nitrous oxide emission reductions from biomass burning are quantified as:

Equation 50

$$\Delta N2O\_bb_{i,t} = N2O\_bb_{bsl,i,t} - N2O\_bb_{wp,i,t}$$

Where:

$\Delta N2O\_bb_{i,t}$	Nitrous oxide emission reductions from avoided or reduced biomass burning for sample unit *i* in year *t*; t CO_2e/unit area
$N2O\_bb_{bsl,i,t}$	Nitrous oxide emissions from biomass burning in the baseline scenario for sample unit *i* in year *t*; t CO_2e/unit area
$N2O\_bb_{wp,i,t}$	Nitrous oxide emissions from biomass burning in the project scenario for sample unit *i* in year *t*; t CO_2e/unit area
i	Sample unit

~~8.5~~8.6 Uncertainty

~~Key sources of uncertainty accounted for are sample error and, where models are applied (Quantification Approach 1), measurement error of model inputs and model prediction error. Uncertainty in area estimation is addressed via complete (and accurate) GIS boundaries of the project area, applying QA/QC procedures specified in the parameter table for A_i.~~

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

~~Total uncertainty deduction, UNC_t, is quantified as:~~

~~**Equation 46**~~

$$\cancel{UN = MIN}$$

~~Where:~~

~~UNC_t~~	~~Uncertainty deduction in year *t* (expressed as the extent to which the half width of the 95% confidence interval, as a percentage of the mean, exceeds the threshold of 15%); unitless number between 0 and 1~~
	~~Sum over pools and gases CO2_soil, C_{TREE}, C_{SHRUB},[34] CH4_SOC, CH4_ent, CH4_md, and N2O_soil, where Quantification Approaches 1 or 2 were employed.~~
~~$s^2_{\Delta \bullet, t}$~~	~~Variance of the estimate of $\Delta \bullet t$. ($\Delta \bullet t$ = mean emission reductions from gas and pool • at time *t*) (see); (t CO2e/unit area)²~~

~~[34] Uncertainty related to quantification of changes in woody biomass are quantified outside of this methodology according to the tool specified in Table 2.~~

	~~Areal average carbon dioxide emission reductions in year t; t CO_2e/unit area~~
	~~Areal average methane emission reductions in year t; t CO_2e/unit area~~
	~~Areal average nitrous oxide emission reductions in year t; t CO_2e/unit area~~
~~T~~	~~Critical value of a student's t-distribution for significance level $\alpha = 0.05$ (i.e., a $1 - \alpha = 95\%$ confidence interval) and the degrees of freedom df appropriate for the design used (e.g., $df = n - 1$ for a simple random sample of n sample units)~~
~~15%~~	~~Threshold beyond which there is an uncertainty deduction~~
~~•~~	~~Gas or pool~~

~~Where Quantification Approach 3 is employed, the uncertainty for that source is intentionally neglectedthe standard error for that source is set equal to zero. Uncertainty calculations for individual gases and pools differ depending on the quantification approach used.~~

~~8.5.1 Quantification Approach 1~~

~~Model prediction error~~

~~Model prediction error is quantified from paired modeled and direct re-measured sites in an experimental sampling regime subject to control and treatment scenarios as:~~

~~Equation 47~~

$$\cancel{s_{struct,\Delta\bullet,t} ==}$$

~~Where:~~

~~$s_{struct,\Delta\bullet,t}$~~	~~(Approximate) standard error in $\Delta\bullet$ ($\Delta\bullet$ = emission reductions in gas and pool •) due to model prediction error at time t; t CO_2e/unit area~~
~~$s_\bullet$~~	~~Standard deviation of the residuals ($\bullet_{measured} - \bullet_{modeled}$). • = modeled or measured emission or stock change in gas and pool • over a fixed interval); t CO_2e/unit area~~
~~$\rho_\bullet$~~	~~Correlation coefficient of (i) model errors in the project scenario and (ii) model errors in the baseline scenario in gas and pool • over a fixed interval; dimensionless~~
~~•~~	~~Gas or pool~~

~~If a performance benchmark is used for the baseline or if the SOC stock is directly remeasured, then $s_{struct,\Delta\bullet,t} ==$.~~

~~It is assumed that the standard deviation $s_{\bullet}$ of the residuals ($\bullet_{measured} - \bullet_{modeled}$) is the same in the control and treatment scenarios. Data for quantifying model prediction error may be sourced from studies conducted external to the project area, and~~area and ~~should be from the same datasets used to validate the model (as detailed in VMD0053 "Model Calibration and Validation Guidance for the Methodology for Improved Agricultural Land Management").~~

~~If the amount of data for quantifying model prediction error varies significantly among crops, soil texture, and climate zones (see VMD0053 "Model Calibration and Validation Guidance for the Methodology for Improved Agricultural Land Management"), then a model prediction error could be estimated for groups of similar sites (e.g., based on a stratification applied to the fields in the project and to the sites in the validation data, or based on a Gaussian Process fit to the validation data with biophysical variables, management practices, and/or other variables as predictors). That way, a model prediction error can be assigned to each sample point i: $s_{struct,\Delta\bullet,i,t}$. Then $s^2_{struct,\Delta\bullet,t}$ is the model error variance for the population, estimated from the $s^2_{struct,\Delta\bullet,i,t}$ using the sample design used. For example, for a simple random sample or for the self-weighting two-stage design described below, is an average of the across i [see (Cochran, 1977)].~~

~~**Model input measurement error**~~

~~Measurement errors of model inputs are automatically captured by the estimate of sample error (discussed below), provided that the measurement errors are uncorrelated across sample points [see, e.g., Cochran (1977, p. 382); de Gruijter et al. (2006, p. 82); (Cochran, 1977); (Gruijter *et al.*, 2006); (Som, 1995)]. QA/QC procedures for model inputs ensure that model inputs are sufficiently accurate and that measurement errors are uncorrelated with each other (see model input requirements in Tables 8.1 and 8.2).~~

~~**Sample and measurement error**~~

~~Here, we give an example of a two-stage design with first-stage units chosen with probability proportional to their acreage (with replacement) and with second-stage units chosen with simple random sampling (with replacement). For example, the first-stage units could be fields that are tiled with a fine grid; the second-stage units are tiles within the grid, and the tiles all have the same area. This design could be modified in many ways, for example by assigning fields to strata, or by eliminating fields as a sampling unit and instead creating strata of tiles.~~

~~In the first stage, n out of N fields are selected with probability proportional to their acreage with replacement. (If a field is chosen multiple times, then tiles are independently selected from that field multiple times.) Subsequent calculations are simplified by making the probability of selecting field i equal to its area A_i divided by the total area of all fields, i.e., probability proportional to size (PPS) sampling:~~

~~**Equation 48**~~

~~=~~

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

~~**Equation 49**~~

~~==~~

~~Where,~~

	~~Areal average unbiased estimator of emissions reduction for gas or pool • in year *t*; t CO_2e/unit area~~
	~~Areal average emissions reduction of gas or pool • in year *t* in field *i*, computed as the average across the sample points in field *i* (areal average), ; t CO_2e/unit area~~
	~~Estimated emissions reduction of gas or pool • in year *t* in field *i*, tile *k* (summed across the whole reporting period for field *i*, tile *k in year t*); t CO_2e/unit area~~
~~m_i~~	~~Number of secondary sampling units (here, tiles) selected to be sampled within field *i*~~
~~n~~	~~Number of primary sampling units (here, fields) selected to be sampled~~
~~i~~	~~Primary sampling unit (here, field)~~
~~k~~	~~Secondary sampling unit (here, tile) within a primary sampling unit (here, field)~~

~~Ignoring model errors, an unbiased estimator of the variance of , is, from [Som (1995), eq. 16.19; (Cochran, 1977), eq. 11.40],~~

~~**Equation 50**~~

~~=~~

~~Where~~

	~~(Approximate) standard error in *Δ•* (*Δ•* = emission reductions in gas and pool •) due to sample error at time *t*; t CO_2e/unit area~~

	~~Area average emissions reduction of gas or pool • in year *t* in field *i*, computed as the average across the sample points in field *i* (areal average), ; t CO_2e/unit area~~
~~,~~	~~Areal average unbiased estimator of variance for gas or pool • in year *t*; t CO_2e/unit area~~
~~*n*~~	~~Number of primary sampling units (here, fields) selected to be sampled~~

~~To fix the amount of work in each field, set m_i equal to constant *m* across all fields. Then the design becomes "self-weighting," and Equation 49Equation 49 simplifies to an average across all measurements, = where is the estimated emissions reduction of gas/pool • at point *k* in field *i*.~~

~~Combined sample and model error~~

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

~~Equation 51~~

$$\cancel{= +}$$

~~Where~~

	~~Variance of the estimate of t. (t = mean emission reductions from gas and pool • at time *t*); (t CO_2e/unit area)^2~~
	~~(Approximate) standard error in *Δ•* (*Δ•* = emission reductions in gas and pool •) due to sample error at time *t*; t CO_2e/unit area~~
	~~(Approximate) standard error in *Δ•* (*Δ•* = emission reductions in gas and pool •) due to model prediction error at time *t*; t CO_2e/unit area~~
~~*m*~~	~~Number of secondary sampling units (here, tiles) selected to be sampled within primary sampling units (here, fields)~~
~~*n*~~	~~Number of primary sampling units (here, fields) selected to be sampled~~

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

~~8.5.2 Quantification Approach 2~~

~~For Quantification Approach 2, where the baseline is represented by a performance benchmark (i.e., a fixed value with no uncertainty), uncertainty is restricted to sample error around stock change in the project scenario.~~

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

~~Equation 52~~

$\cancel{= *}$

$\cancel{s^2_{\Delta \bullet,t}}$	~~Variance of the estimate of $\Delta \bullet t$. ($\Delta \bullet t$ = mean emission reductions from gas and pool • at time t); (t CO_2e/unit area)^2~~
$\cancel{s^2_{\bullet,wp,t}}$	~~Variance of •$_{wp,t}$ (• = emissions from gas or pool •) in the project scenario at time t; (t CO2e/unit area)^2~~
$\cancel{s^2_{\bullet,wp,t-1}}$	~~Variance of •$_{wp,t}$ (• = emissions from gas or pool •) in the project scenario at time t-1; (t CO2e/unit area)^2~~
$\cancel{Cov(\bullet_{wp,t}, \bullet_{wp,t-1})}$	~~Covariance of •$_{wp,t}$ and •$_{wp,t-1}$; (t CO2e/unit area)^2~~
$\cancel{n}$	~~Number of primary sampling units (here, fields) selected to be sampled~~
	~~Gas or pool~~

~~For Quantification Approach 2, where the baseline is directly measured in baseline control sites, uncertainty is restricted to sample error around stock change in the project and baseline scenarios.~~

~~Equation 53~~

$$\cancel{s^2_{\Delta \bullet,t} = \frac{1}{n} * \left(s^2_{\bullet,wp,t} + s^2_{\bullet,wp,t-1} - 2 * Cov\left(\bullet_{wp,t}, \bullet_{wp,t-1}\right)\right)}$$

8.6.1 Quantification Approach 1

There are two approaches available to estimate the uncertainty: analytical calculation of error propagation and Monte Carlo simulation.

8.6.1.1 Analytical Calculation of Error Propagation

In error propagation, the uncertainty characterized by the variances is propagated through the calculation to estimate the variance of the final fluxes. Note the method requires at least two sample units, but the uncertainty will decrease as the number of sample units increases.

Calculations for SOC

The SOC flux from changes in SOC depend on differences in SOC stocks between two points in time, i.e., the uncertainties at both times influence the estimate of the flux.

$\overline{D_{SOC}}$ (t CO2e/ha) is the mean difference with and without practice change at one time, and is calculated in Equation 51.

Equation 51

$$\overline{D_{SOC,i,t}} = \overline{SOC_{i,wp,t}} - \overline{SOC_{i,bsl,t}}$$

Where:

$SOC_{i,wp,t}$	SOC stock for the project for sample unit, *i*, at time, *t*; t CO_2e/unit area
$\overline{SOC_{i,bsl,t}}$	mean SOC stock from the baseline for sample unit, *i*, at time, *t*; t CO_2e/unit area

The mean change in SOC stock (t CO_2e/unit area) from Equation 52 ~~E~~is for the number of sample units for which estimates are modeled. To reduce computational effort, the mean may be calculated for a subset of sample units. This should be done with simple random sampling with replacement. The fewer the number of sample units included the higher will be the expected uncertainty since it includes sampling uncertainty. The lowest uncertainty is expected if all the sample units are estimated since then no uncertainty introduced by sampling. The mean change in SOC stocks over time is

Equation 52

$$\overline{\Delta SOC} = \sum_{i=1}^{n} a_i\left(\overline{D_{SOC,i,t}} - \overline{D_{SOC,i,t\_previous}}\right)$$

Where:

ΔSOC	mean change of SOC stocks since the previous measurement period (start of the crediting period); t CO_2e/unit area
n	number of sample units included, $n \leq$ total number of sample units; unitless

$\overline{D_{SOC,i,t}}$ mean SOC stock difference with and without practice change at the end of year *t*; t CO_2e/unit area

$\overline{D_{SOC,i,t\_previous}}$ mean SOC stock difference with and without practice change at the previous measurement year *t_previous*; t CO_2e/unit area

a_i relative area of sample unit *i*; unitless

With the relative area a_i:

Equation 53

$$a_i = \frac{A_i}{\sum_{i=1}^{n} A_i}$$

Where:

A_i area of the sample unit *i*; unit area

Any error in the land areas would affect uncertainty of total sources or sinks but these are provided by land managers so assumed to be negligible. Further, assuming these areas remain the same over time, any error does not affect the per unit area difference between baseline and project, it only affects the upscaled difference.

The overall project variance is the sum of the variance for units and the variance for prediction is calculated using Equation 54.

Equation 54

$$s^2_{\overline{\Delta SOC_{unit}}} = \frac{\sum_{i=1}^{n}\left[a_i^2\left(\left(D_{SOC,i,t} - \overline{D_{SOC,t}}\right)^2 + \left(D_{SOC,i,t-1} - \overline{D_{SOC,t\_previous}}\right)^2\right)\right]}{(n-1) * \sum_{i=1}^{n} a_i^2}$$

The variance of the prediction, $s^2_{model,D_{SOC}}$, is derived from the effect of uncertainty of model inputs (initial SOC, soil texture, precipitation, land management, etc.) on modeled outputs.

The model prediction error is derived from the discrepancy between measured and modeled values of the flux difference after practice change for the data used for model validation ("goodness of fit", see VMD0053). The model prediction error includes the combined effect of model structural uncertainty (inadequacy of the model), uncertainty of measured data used for validation, and model output uncertainty from the error in the model inputs used in the validation. In practice, these components of model prediction error are difficult to separate so are pooled into a single variance.

Assuming that $s^2_{pred,D_{SOC}}$ is the same at different times and not correlated across time, then the prediction of variance of mean $\overline{\Delta SOC}$ is calculated as:

Equation 55

$$s^2_{pred,\overline{\Delta SOC}} = \frac{\sum_{i=1}^{N_{wp}} 2\, a_i^2 s^2_{pred,D_{SOC}}}{n}$$

The baseline and project scenarios have the same SOC stocks, so the variance for the first crediting period is $s^2_{pred,\overline{\Delta SOC}} = \frac{\sum_{i=1}^{Nwp} a_i^2 s^2_{pred,D_{SOC}}}{N_{wp}}$.

Model data input errors

The land management data can be an important source of error if not well known. However, projects have the ability to verify the land management data with records provided by land managers, so this is not expected to be a major source of error. The management data for the baseline scenario is derived from historical management data for each field, so, for the purposes of VM0042, there is no uncertainty in the baseline management. The input data uncertainty of physical input data (precipitation, soil texture, SOC, etc.) has been found to be insignificant compared to the model prediction error (Peltoniemi *et al.*, 2006; Ogle *et al.*, 2010).

Initial SOC stock can be an important cause of uncertainty for SOC change, as well as soil fluxes of N_2O and CH_4. However, because both baseline and project scenarios are modelled and their differences are calculated over time, the effect of the initial conditions largely cancel out (FAO, 2019). Further, the initial quantity of SOC for both the baseline and the project is measured, greatly reducing the uncertainty of the initial SOC conditions.

Providing other physical input data are derived from the best available sources, the effect on their uncertainty on model outputs decreases as the size of the land area increases due to averaging out of the effects of physical input data over the large land area (Peltoniemi *et al.*, 2006; Nol *et al.*, 2010). Importantly, the physical input data (other than management data) are identical for project and baseline, so their uncertainty cancels out when the outputs for the modeled baseline is subtracted from those for the project. As such, when using official government data for physical input data like weather and soil properties in the context of modelled fluxes from the project minus that for the baseline, the impact of model input data uncertainty can be neglected. Therefore, the estimate prediction error, $s^2_{pred,D_{SOC}}$, will be that of the model prediction error, $s^2_{model,D_{SOC}}$, as estimated from the validation:

Equation 56

$$s^2_{pred,D_{SOC}} \approx s^2_{model,D_{SOC}}$$

If the amount of data for quantifying model prediction error varies significantly among crops, soil texture, and climate zones (see section 5.2, VMD0053), then a model prediction error could be estimated for groups of similar sites (e.g., based on a stratification applied to the fields in the project and to the sites in the validation data, or based on a Gaussian Process fit to the validation data with biophysical variables, management practices, and/or other variables as predictors). That way, a model prediction error can be assigned to each sample unit i: $s^2_{pred,D_{SOC},i}$

The total uncertainty of the mean SOC stock change for sample units is the sum of that for measured/modelled sample units and that for prediction.

Equation 57

$$s^2_{\Delta SOC} = s^2_{\overline{\Delta SOC_{unit}}} + f * s^2_{pred,D_{SOC}}$$

Where:

$s^2_{\Delta SOC}$	is the uncertainty of the mean change in SOC between project and baseline since the previous measurement
f	factor that distinguishes between crediting periods for SOC.
	f=1 for first crediting period for C stock changes since the baseline and project had the same C stocks initially.
	f=2 for SOC for the second and subsequent crediting period since it requires difference in stocks at two times to determine the flux.

Calculations for N_2O and CH_4 emissions

Where differences in N_2O and/or CH_4 emissions are estimated using Quantification Approach 1, the calculation approach is similar to that for SOC stocks, with the only divergence that the estimate of prediction error is reduced by factor 2.

The difference in fluxes is calculated as:

Equation 58

$$\overline{\Delta \bullet_t} = \sum_{i=1}^{n} a_i * \left(\overline{\Delta \bullet_{i,wp,t}} - \overline{\Delta \bullet_{i,bsl,t}}\right)$$

The variance from sample units is calculated as:

Equation 59

$$s^2_{\overline{\Delta \bullet_{t,units}}} = \frac{\sum_{i=1}^{n}\left[a_i * \left(\Delta \bullet_{i,t} - \overline{\Delta \bullet_t}\right)^2\right]}{(n-1) * \sum_{i=1}^{n} a_i^2}$$

The variance for prediction of mean gas flux difference, is calculated as:

Equation 60

$$s^2_{\overline{\Delta \bullet_t}} = \frac{\sum_{i=1}^{n} a_i^2 s^2_{pred,\Delta \bullet_t}}{n}$$

Where:

$s^2_{pred,\Delta \bullet_t}$ is the model error variance for the difference between fluxes with and without practice change derived from model validation (VMD0053).

Example: Two-Stage Proportional Probability Sampling with Replacement (PPSWR)

The project may be divided into project subsections, or primary tiles, such as strata or fields, and then these primary tiles further divided into secondary tiles that are the sample units. The attributes of the secondary tiles are estimated from an individual sample point within the secondary tile. The model input data will be different for each selected sample point based on the heterogeneity within the primary tile.

Here, we give an example of a two-stage design where 1) a subset of all primary tiles in the project are selected randomly (first stage) and 2) sample points within the primary tiles are selected randomly for modeling (second stage). For the first-stage sampling, the probability of selecting a particular primary tile for estimation of emissions and removals will be the probability proportional to their acreage (with replacement). The first stage sampled primary tiles are subdivided into tiles that are subsections of the primary tile. For example, the first stage sampled tiles could be fields that are tiled with a fine grid; the second-stage units are tiles within the grid, and the secondary tiles all have the same area. The sample points are within an individual secondary tile.

The purpose of the design is to better capture the heterogeneity of model inputs within the project. Therefore, this design could be modified in many ways depending on knowledge of heterogeneity over the project area. For example, it could be modified by assigning fields to strata, or by eliminating fields as a sampling unit and instead creating strata of tiles.

In the first stage, n out of N fields are selected with a probability proportional to their acreage with replacement. If a field is selected multiple times, then secondary tiles are independently selected from that field multiple times. Subsequent calculations are simplified by making the probability of selecting field *i* equal to its area A_i divided by the total area A_0 of all fields, i.e., probability proportional to size (PPS) sampling:

Equation 61

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

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

Equation 62

$$\overline{\Delta \bullet_t} = \frac{1}{n}\sum_{i=1}^{n}\overline{\Delta \bullet_{i,t}} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{m_i}\sum_{k=1}^{m_i}\Delta \bullet_{i,k,t}$$

Where:

$\overline{\Delta \bullet_t}$	Areal average unbiased estimator of emissions reduction for gas or pool • in year t; t CO_2e/unit area
$\overline{\Delta \bullet_{i,t}}$	Areal average emissions reduction of gas or pool • in year t in field i, computed as the average across the sample points in field i (areal average), $(1/m_i)\sum_{k=1}^{m_i}\Delta \bullet_{i,k,t}$ t CO_2e/unit area
$\Delta \bullet_{i,k,t}$	Estimated emissions reduction of gas or pool • in year t in field i, tile k (summed across the whole reporting period for field i, tile k in year t); t CO_2e/unit area
m_i	Number of secondary tiles selected to be sampled within field i
n	Number of primary tiles (here, fields) selected to be sampled
i	Primary tile (here, field)
k	Secondary tile within a primary tile (here, field)

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

Equation 63

$$s^2_{\text{sampling},\Delta\bullet,t} = \frac{\sum_{i=1}^{n}\left(\overline{\Delta \bullet_{i,t}} - \overline{\Delta \bullet_t}\right)^2}{n(n-1)}$$

Where:

$s^2_{\text{sampling},\Delta\bullet,t}$ (Approximate) standard error in $\Delta\bullet$ ($\Delta\bullet$ = emission reductions in gas and pool $\bullet$) due to sample error at time t; t CO_2e/unit area

$\overline{\Delta\bullet}_{i,t}$ Area average emissions reduction of gas or pool • in year t in field i, computed as the average across the sample points in field i (areal average), $(1/m_i)\sum_{k=1}^{m_i}\Delta\bullet_{i,k,t}$ t CO_2e/unit area

$\overline{\Delta\bullet}_{t}$, Areal average unbiased estimator of variance for gas or pool • in year t; t CO_2e/unit area

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

To fix the amount of measurement effort in each field, set m_i equal to constant m across all fields. Then the design becomes "self-weighting," and simplifies to an average across all measurements, $\overline{\Delta\bullet}_t = \frac{1}{n\,m}\sum_{i=1}^{n}\sum_{k=1}^{m}\Delta\bullet_{i,k,t}$ where $\Delta\bullet_{i,k,t}$ is the estimated emissions reduction of gas/pool • at point k in field i.

Combined sample and model error for sample units

To incorporate model errors, we assume that they are uncorrelated with the input data in the sample, and we assume that model errors are independent across samples. Then, the variance of $\overline{\Delta \bullet}_t$ incorporating sample uncertainty and model prediction uncertainty is:

Equation 64

$$s^2_{\Delta\bullet,t} = f * s^2_{\text{sampling},\Delta\bullet,t} + \frac{f \times \ s^2_{pred}}{n_1 \ \times \ m}$$

Where:

$s^2_{\Delta\bullet,t}$	Variance of the estimate of $\overline{\Delta \bullet}\ t$. ($\overline{\Delta \bullet}\ t$ = mean emission reductions from gas and pool • at time *t*); (t CO_2e/unit area)[2]
$s^2_{\text{sampling},\Delta\bullet,t}$	(Approximate) standard error in *Δ•* (*Δ•* = emission reductions in gas and pool •) due to sample error at time *t*; t CO_2e/unit area
s^2_{pred}	(Approximate) standard error in *Δ•* (*Δ•* = emission reductions in gas and pool •) due to model prediction error, t CO_2e/unit area
f	factor that distinguishes between crediting periods for SOC. *f=1* for first crediting period for C stock changes since the baseline and project had the same C stocks initially. *f*=2 for SOC for the second and subsequent crediting period since it requires difference in stocks at two times to determine the flux. *f=1* for N_2O or CH_4 estimated by quantification approach 1 since it is flux over time.
m	Number of sample units (here, secondary tiles) selected to be sampled within primary tiles (here, fields)
n_1	Number of primary tiles (here, fields) selected to be sampled

When SOC stock change is periodically directly re-measured in the project scenario (i.e., “true-up”), model (input and prediction error) uncertainty is only accounted for in the baseline scenario.

8.6.1.2 Monte Carlo Method for Error Propagation

As for the analytical method for error propagation, the model prediction error is derived from the discrepancy between measured and modeled values of the flux difference after practice change for the data used for model validation (“goodness of fit”, see VMD0053).

To determine the "goodness of fit" between measured and modeled values of the flux difference, a posterior predictive distribution is developed. For each sample unit, a random draw of the posterior predictive distribution is taken indexed by l, from 1 to L. Each of these are called a Monte Carlo (MC) simulation.

Model input uncertainty from physical inputs, which are the same for both baseline and project scenarios, such as precipitation, soil texture, initial soil organic carbon percent, can be included through additional MC simulations from assumed distributions for these inputs (Kennedy and O'Hagan, 2001). However, the impact of the final variance, as discussed in section 8.6.1.1., does not warrant the substantial computational cost.

MC simulation methods are commonly used in Bayesian analyses, which have gained popularity as a framework for calibrating deterministic, process-based biogeochemical models of soils and agroecosystems and estimating the uncertainty of biogeochemical model predictions (Kennedy and O'Hagan, 2001; Gurung *et al.*, 2020). MC simulation method is suitable for nonlinear, deterministic, process-based biogeochemical models (e.g., DayCent, DNDC) because, unlike the analytic error propagation method, the MC method can more easily address key dependencies in the 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 (Ogle *et al.*, 2007, 2010; Gurung *et al.*, 2020).

Let $\tilde{y}_{i,l}$ represent one of the MC simulations of a particular flux difference in tons of carbon dioxide equivalent (tCO_2e) per unit area at sample unit i. Equation 65 to Equation 69 require that sample units have a defined area. If the sample unit is defined as a point (location with no defined area), then a subsample of the project is modeled, and the sampling error is quantified with Equation 70 to Equation 74.

Then, the total flux difference for that sample unit can be calculated using Equation 65. Note that the areas of each sample unit are known fixed quantities.

Equation 65

$$A_i\hat{y}_i = \frac{A_i}{L}\sum_{l=1}^{L}\tilde{y}_{il}$$

Where:

$\tilde{y}_{il}$ flux difference for sample unit i and MC simulation l (tCO_2e per area unit)

$\hat{y}_i$ MC estimates of mean flux difference for sample unit i (tCO_2e per area unit)

A_i total area of sample unit i

L total number of MC simulations

Similarly, the variance of the total flux difference for that sample unit can be approximated by using Equation 66.

Equation 66

$$\frac{A_i^2}{L-1} = \sum_{l=1}^{L} (\tilde{y}_{il} - \hat{y}_i)^2$$

Where:

$\tilde{y}_{il}$ flux difference for sample unit i and MC simulation l (tCO_2e per area unit)

$\hat{y}_i$ MC average flux difference of sample unit i (tCO_2e per area unit)

A_i Total area of sample unit i

L total number of MC simulations

Note that for biogeochemical models the variance estimate at one sample unit is expected to be large, resulting in a potentially large uncertainty deduction. However, this uncertainty shrinks when many sample units form a project and uncertainty of the average over the population of sample units in the project is computed. MC simulations of the average flux difference over the project can be computed from the MC simulations from each sample unit using Equation 67.

Equation 67

$$\bar{y}_l = \frac{1}{A} \sum_{i=1}^{N} A_i \tilde{y}_{il}$$

Where:

$\tilde{y}_{il}$ flux difference for sample unit i and MC simulation l (tCO_2e per area unit)

A_i total area of sample unit i

$\bar{y}_l$ total average flux difference over the project for MC simulation l (tCO_2e per area unit)

N number of all sample units in the project

A total project area (sum of areas from all sample units)

The project level MC simulations ($\bar{y}_l$) of total average flux differences by source/sink over the project can be summed across all sources/sinks to get the total for all gasses ($\bar{T}_l$). The mean and a percentile can then be calculated from these project level MC simulations for all gasses using Equation 68 and Equation 69 for use in the uncertainty deduction Equation 83 or Equation 85.

Equation 68

$$\overline{\Delta F_t} = \frac{1}{L}\sum_{l=1}^{L}\bar{T}_l$$

Where:

$\bar{T}_l$ total average flux difference for all gasses for MC simulation l (tCO_2e per area unit)

L total number of MC simulations

Equation 69

$$\overline{\Delta F}_{t,p} = \bar{T}_{[h_f]} + (h - h_f) * \left(\bar{T}_{[h_c]} - \bar{T}_{[h_f]}\right)$$

Where:

L total number of MC simulations

p percentile as a decimal (e.g., 0.025 for 2.5th percentile)

h $\left(L+\frac{1}{3}\right)p+\frac{1}{3}$ *

h_f nearest integer less h (e.g., floor function of h)
h_c nearest integer greater h (e.g., ceiling function of h)

$\bar{T}_{[i]}$ the i^{th} ordered MC simulation of total average flux difference for all gasses (tCO_2e per area unit), in the above i takes the value h_f or h_c

Parameter h refers to (Hyndman and Fan, 1996) recommended interpolation, but they also report eight other common methods implemented in software, which would give sufficiently similar results when the simulation size is large enough (L>=100). The method (one of the nine discussed in (Hyndman and Fan, 1996)) should be documented by the project developer and evaluated as part of the Independent Evaluation Expert (IEE) assessment.

Sampling Error

For large projects where sampling all sample units in the project is cost-prohibitive, probability sampling can be used to estimate the total ERRs by only modeling a fraction of the sample units in the project. However, the sampling design introduces uncertainty, and this source of uncertainty must be appropriately estimated and propagated to the total uncertainty.

Sampling designs can be simple or complex. Examples include simple random sampling, probability proportion to size, stratified sampling, multi-stage sampling, or a combination of these methods (see section 9.3.1 for further guidance and (Cochran, 1977) for more examples).

The total uncertainty in the population-level estimate of total ERRs then results from both the model uncertainty, (which includes measurement errors, for derivation see the Supplemental Materials for (Gurung *et al.*, 2020)) reflected in MC simulation of the model, and the uncertainty based on the sampling design. Using standard variance decomposition (i.e., the law of total variance), the total variance can be decomposed as:

Equation 70

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

Where:

$\mathbb{E}[\mathrm{Var}(\hat{\tau}\|\boldsymbol{s})]$	Estimate of model uncertainty which is the expectation of the conditional variance given the sample design.
$\mathrm{Var}(\mathbb{E}[\hat{\tau}\|\boldsymbol{s}])$	Estimate of the uncertainty due to sampling design, i.e., the variance of the conditional expectation.
$\boldsymbol{s}$	the realized sample, selected using the sample design

In Equation 70, using variance decomposition, the total variance is completely defined by the model uncertainty given the random sample from the sample design $(E[Var(\hat{\tau}|s)])$ and the uncertainty due to random sample draw $\left(Var(E[\hat{\tau}|s])\right)$ using the Monte Carlo mean estimates.

Example 1: One-stage Simple Random Sample with Replacement (SRSWR)

In a simple random sample with replacement (SRSWR) design, a random selection of sample units is drawn from the known population of sample units. Let A be the total area of the project and i = 1…,n are the random selection of sample units. Then, the total ERRs estimate and the associated variance are estimated by Equation 71 and Equation 72:

Equation 71

$$\hat{\tau} = \frac{A_0}{n \times L}\sum_{i=1}^{n}\sum_{l=1}^{L}\tilde{y}_{il}$$

Where:

$\hat{\tau}$	Monte Carlo estimate (MC mean) of total GHG emissions reductions for the project
$\tilde{y}_{il}$	GHG emissions reduction for sample unit i and MC simulation l (tCO_2e / unit area)

A_0 total area of the project

And $\hat{\mu} = \hat{\tau}/A$ is the average GHG emission reduction (tCO2e / unit area):

Equation 72

$$\widehat{\mathrm{Var}}(\hat{\tau}) = \frac{{A_0}^2}{n \times (n-1)} \sum_{i=1}^{n} (\hat{y}_i - \hat{\mu})^2 + \frac{1}{L-1} \sum_{l=1}^{L} (\tilde{\tau}_l - \hat{\tau})^2$$

Where:

$\hat{\tau}$ MC estimate of total GHG emission reductions for the project (tCO_2e)

$\tilde{\tau}_l$ total GHG emission reductions for the l^{th} MC simulation of the project (tCO_2e)

$\hat{y}_i$ MC estimate of GHG emission reductions at sample unit i (tCO_2e per unit area)

A_0 total area of the project

n number of randomly selected sample units

L number of MC simulations

The variance of the areal average GHG emission reduction $\left(\widehat{\mathrm{Var}}(\hat{\mu})\right)$ is obtained by dividing $\widehat{\mathrm{Var}}(\hat{\tau})$ by A^2.

Example 2: Two-Stage PPSWR-SRSWR Design

In a two-stage sampling design, there are two sizes of units, one nested within the other. For this example, the large unit is a called a field and the smaller unit is called a point. The smaller units (points) are the project sample units, which do not have equal sampling probabilities. In the first stage, n_1 fields out of N fields are randomly selected with probability proportional to size (i.e., area) with replacement (PPSWR). In the second stage, m_i points are drawn from each of the n fields selected in the first stage using simple random sample with replacement (SRSWR). For this design, the estimate of the total ERRs and its variance estimates are provided by Equation 73 and Equation 74, respectively.

Equation 73

$$\hat{\tau} = \frac{A_0}{n} \sum_{i=1}^{n} \left(\frac{1}{m_i} \sum_{j=1}^{m_i} \left(\frac{1}{L} \sum_{l=1}^{L} \tilde{y}_{ijl} \right) \right)$$

Where:

$\hat{\tau}$ MC estimate (MC mean) of total GHG emissions reductions for the project

$\tilde{y}_{ijl}$ GHG emissions reduction for field i, point j, and MC simulation l (tCO_2e per unit area)

A_0 total area of the project

and $\hat{\mu} = \hat{\tau}/A$ areal average GHG emission reduction (tCO2e/unit area)

Equation 74

$$\widehat{\mathrm{Var}}(\hat{\tau}) = \frac{{A_0}^2}{n \times (n-1)} \sum_{i=1}^{n} (\hat{y}_i - \hat{\mu})^2 + \frac{1}{L-1} \sum_{l=1}^{L} (\tilde{\tau}_l - \hat{\tau})^2$$

Where:

$\hat{\tau}$ MC estimate of total GHG emission reductions for the project (tCO_2e)

$\tilde{\tau}_l$ total GHG emission reductions for the l^{th} MC simulation of the project (tCO_2e)

$\hat{y}_i$ MC estimate of areal mean GHG emission reductions of field i (tCO_2e per unit area)

A_0 total area of the project

n number of sample points

L number of MC simulations

and the variance of the average ERRs $\left(\widehat{\mathrm{Var}}(\hat{\mu})\right)$ is obtained by dividing $\widehat{\mathrm{Var}}(\hat{\tau})$ by A^2.

Monte Carlo Error

The accuracy of the MC estimates depends on the number of independent MC draws. When MC draws are done using 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), page 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 only a factor of 1.005, implying that the MC error adds almost nothing to the uncertainty estimation. More than 100 simulations can add numerical stability to estimates, particularly for the percentile summaries (Equation 69). (Gelman *et al.*, 2014) suggested a choice of L between 100 to 2,000.

8.6.2 Quantification Approach 2

Quantification Approach 2 is applicable for SOC stocks only and has the baseline represented by control sites that are linked to one or more project sample units. The SOC stock difference and its uncertainty is calculated based on the pairs of control sites linked with their project sample units. A project site is defined as the aggregation of all the linked sample units in the project that are paired with a single control site.

Note that the method requires at least 2 pairs of control sites-project sites, but more pairs will decrease uncertainty, particularly when number of pairs is less than 10.

The area of each project site is:

Equation 75

$$A_{ps,c} = \sum_{i=1}^{N_{i,c}} A_i$$

Where:

$A_{ps,c}$ area of each project site in each pair, c, of project site with control site: unit area

A_i area of a sample unit *i*: unit area

$N_{i,c}$ number of sample units in each project site in pair, c

Therefore, the area weighted mean SOC stocks of sample units with each project site is:

Equation 76

$$\overline{SOC_{ps,c,t}} = \frac{\sum_{s=1}^{N_{i,c}} A_i * SOC_{ps,c,s,t}}{\sum_{s=1}^{N_{i,c}} i}$$

Where:

$\overline{SOC_{ps,c,t}}$ is the mean SOC stock for project site in pair, c at current time, *t*; (t CO_2e/unit area)

$SOC_{ps,c,s,t}$ is the SOC stock in each sample unit in the project site in pair, c at current time, t; (t CO_2e/unit area)

The relative area of each project site is:

Equation 77

$$a_{ps,c} = \frac{A_{ps,c}}{\sum_{c=1}^{N_c} A_{ps,c}}$$

The project area-weighted mean difference in SOC stocks between the project site and the control site from the before the current time is:

Equation 78

$$\overline{\Delta SOC_t} = \sum_{c=1}^{N_c} a_{ps,c}\left[\left(SOC_{ps,c,t} - SOC_{ps,c,t\_previous}\right) - \left(SOC_{bsl,c,t} - SOC_{bsl,c,t\_previous}\right)\right]$$

Where:

$\overline{\Delta SOC_t}$, = is area-weighted mean difference in SOC stocks between the project site and the control site from the previous to the current time; (t CO_2e/unit area)

Equation 79

$$s^2_{\overline{\Delta SOC_t}} = s^2_{\overline{ps,t}} + s^2_{\overline{ps,t_{previous}}} + s^2_{\overline{bsl,t}} + s^2_{\overline{bsl,t\_previous}} - 2Cov\left(SOC_{bsl,t}, SOC_{bsl,t\_previous}\right) - 2Cov\left(SOC_{ps,t}, SOC_{ps,t\_previous}\right) - 2Cov\left(SOC_{bsl,t}, SOC_{ps,t}\right) - 2Cov\left(SOC_{bsl,t\_previous}, SOC_{ps,t\_previous}\right) + 2Cov\left(SOC_{bsl,t\_previous}, SOC_{ps,t}\right) + 2Cov\left(SOC_{bsl,t}, SOC_{ps,t\_previous}\right)$$

Where:

$s^2_{\overline{\Delta SOC_t}}$ = is the variance of the mean difference in SOC stocks between the project site and the control site from the before the current time; (t CO_2e/unit area)[2]

$s^2_{\overline{ps,t}}$, $s^2_{\overline{ps,t\_previous}}$, $s^2_{\overline{bsl,t}}$, $s^2_{\overline{bsl,t\_previous}}$ = are the variances of mean SOC stocks for the project site at the current time, for the project site at the previous time, for the control site at the current time and for the control site at the previous time, respectively; (t CO_2e/unit area)[2]

$Cov\left(SOC_{bsl,t}, SOC_{bsl,t\_previous}\right)$ = is the covariance of between the SOC stocks for the control site at the current and previous time; (t CO_2e/unit area)[2]

$Cov\left(SOC_{ps,t}, SOC_{ps,t\_previous}\right)$ = is the covariance of between the SOC stocks for the project site at the current and previous time; (t CO_2e/unit area)[2]

$Cov\left(SOC_{bsl,t}, SOC_{ps,t}\right)$ = is the covariance of mean SOC stocks between the control site and the project site at the current time; (t CO_2e/unit area)[2]

$\mathrm{CCov}(\mathrm{SOC}_{\mathrm{bsl,t\_previous}}, \mathrm{SOC}_{\mathrm{ps,t\_previous}})$ is the covariance of SOC stocks between the control site and the project site at the previous time; (t CO_2e/unit area)^2

$\mathrm{Cov}(\mathrm{SOC}_{\mathrm{bsl,t\_previous}}, \mathrm{SOC}_{\mathrm{ps,t}})$ is the covariance of SOC stocks between the control site at previous time and the project control site at the current time; (t CO_2e/unit area)^2

$\mathrm{Cov}(\mathrm{SOC}_{\mathrm{bsl,t}}, \mathrm{SOC}_{\mathrm{ps,t\_previous}})$ is the covariance of SOC stocks between the control site at the current time and the project control site at the previous time; (t CO_2e/unit area)^2

The variances are calculated from SOC stocks for project area weighted pairs of control site with project site. An example of calculation of variance is shown below for the case of project site at current time:

Equation 80

$$s_{ps,t}^2 = \frac{\sum_{c=1}^{N_c} a_{ps,c}\left(SOC_{ps,c,t} - \overline{SOC_{ps,t}}\right)^2}{(N_c - 1)}$$

Where:

$\overline{\mathrm{SOC}_{\mathrm{ps,t}}}$ is the mean SOC stocks for project sites at current time, t: (t CO_2e/unit area)

The covariances are calculated from SOC stocks for project area weighted pairs of control site with project site. An example of calculation of covariance is shown below for the case between the baseline at current time and project site at current time:

Equation 81

$$Cov\left(SOC_{bsl,t}, SOC_{ps,t}\right) = \frac{\sum_{c=1}^{N_c} a_{ps,c}\left(SOC_{bsl,c,t} - \overline{SOC_{bsl,t}}\right)\left(SOC_{ps,c,t} - \overline{SOC_{ps,t}}\right)}{(N_c - 1)}$$

Where:

$\overline{\mathrm{SOC}_{\mathrm{bsl,t}}}$ is the mean SOC for control sites at current time, t; (t CO_2e/unit area)

8.6.3 Estimating ~~t~~Total Uncertainty of ERRs

The mean total of flux changes across all sources and sinks having uncertainty estimates, $\overline{\Delta F_t}$ (t CO2e/ unit area), at time, t, is calculated using Equation 82.

Equation 82

$$\overline{\Delta F_t} = \sum_{SS_t} \overline{SS}_t$$

Where $\overline{SS}_t$ is the mean flux (t CO2e/unit area) for individual or sums of sources and sinks, at time *t*. The sources or sinks include changes in SOC stocks, C pools in trees (C_{TREE}) and shrubs (C_{SHRUB}), fossil fuel emissions for land management practices, N_2O emissions, and CH_4 emissions.

The uncertainty of $\overline{\Delta F_t}$ is estimated from the set percentiles for the probability distribution function of values of $\overline{\Delta F_t}$. For the analytical error propagation approach, this is done based on the pooled variance and assuming a t-distribution for the probability density function. For the Monte Carlo simulation, these percentiles are extracted from the produced probability distribution function of values of $\overline{\Delta F_t}$.

8.6.4 Uncertainty Deduction

Two cases depending on the Quantification Approach used for estimating Direct N_2O Emissions

1. Case N1 is when Quantification Approach 1 is used for estimating direct N_2O emissions. Soil C and N cycling are inextricably linked, so anything that affects soil C cycling will affect soil N cycling and thereby also affect N_2O emissions. Because Quantification Approach 1 requires calibration and validation for the project domain, there is higher confidence in the accuracy of N_2O emission estimates.

2. Case N3 is when Quantification Approach 3 is used for N_2O emission estimates. These methods are not specifically validated for the project domain, so there is less confidence in the accuracy and that the direct N_2O emissions are not causing overestimates of ERRs for the project. Further, the total uncertainty used for deduction under case N3 is only that for SOC and so the total uncertainty is always less than for case N1 for which the uncertainty for N_2O emissions is included to calculate an uncertainty deduction. Under case N3, the deduction based only on SOC uncertainty must account for impact of uncertainty of N_2O emissions in addition those on SOC (as well as the effects of the uncertainties of all other emission sources). Therefore, the uncertainty deduction for case N3 that is based on SOC uncertainly alone needs to be greater than the uncertainty deduction based on combined SOC and direct N_2O uncertainty for case N1.

Two Pathways for uncertainty deduction

There are two pathways to calculate the uncertainty deduction. Pathway A uses a deduction based on the relative uncertainty, while pathway B is based on a value for ERRs that is less than the mean for which there is a set probability that the estimate will be exceeded (i.e., probability of exceedance). Both pathways A and B have two cases with different deductions for uncertainty.

1. Pathway A: Relative uncertainty

Pathway A is based on the relative uncertainty of the sum of sources and sinks for the project minus the baseline. The relative uncertainty is estimated as one-half of the confidence limit divided by the sum of differences in sources and sinks between the project and baseline. If the relative uncertainty is greater than a threshold, A, there is an uncertainty deduction:

- For case N1, the defined threshold is 15%. When the relative uncertainty is lower than 15%, no uncertainty deduction comes into effect.
- For case N3, A is defined as 0%, so that there is always a deduction for uncertainty.

Equation 83

$$UNC_t = MIN\left(100\%, MAX\left(0, \frac{\left(\overline{\Delta F}_{t,0.975} - \overline{\Delta F}_{t,0.025}\right)/2}{\overline{\Delta F}_t} * 100\% - A\right)\right)$$

Where:

UNC_t	Uncertainty deduction in year *t* (expressed as the extent to which the half width of t interval, as a percentage of the mean, exceeds the threshold of A%); % between 0 and 100
A	Defined threshold beyond which there is an uncertainty deduction that depends on the case of completeness of the uncertainty calculation. For case N1, A is 15% For case N3, A is 0%

For the Monte Carlo simulation error propagation approach, the values for $\overline{\Delta F}_{t,0.975}$ and $\overline{\Delta F}_{t,0.025}$ are calculated using Equation 69, with p=0.975 and p = 0.025, respectively. Alternatively, the same approach as for the analytical error propagation can be used, as an approximation, and individual variances $s^2_{\Delta\bullet,t}$ are calculated using Equation 70 and the applied sample design.

For the analytical error propagation, these values are derived from the t distribution:

Equation 84

$$\overline{\Delta F}_{t,0.975} = T_{0.975}\sqrt{\textstyle\sum_{\bullet} s^2_{\Delta\bullet,t}} \text{ and } \overline{\Delta F}_{t,0.025} = T_{0.025}\sqrt{\textstyle\sum_{\bullet} s^2_{\Delta\bullet,t}}$$

Where:

$s^2_{\Delta\bullet,t}$	Variance of the estimate of $\Delta \bullet t$. ($\Delta \bullet t$ = mean emission reductions from gas and pool • at time t) (see); (t CO2e/unit area)[2] (IPCC, 2019)
T	Critical value of a student's t-distribution for significance level $\alpha = 0.975$ and 0.025 with $df = n - 1$ for a simple random sample of n sample units)

2. Pathway B: probability of exceedance

Pathway B has an uncertainty deduction based on a defined threshold in the estimated probability density function. This enables a judgement to which extent (B%) the sum of achieved ERRs by the project can be expected to be accurate. Figure 2 demonstrates the concept.

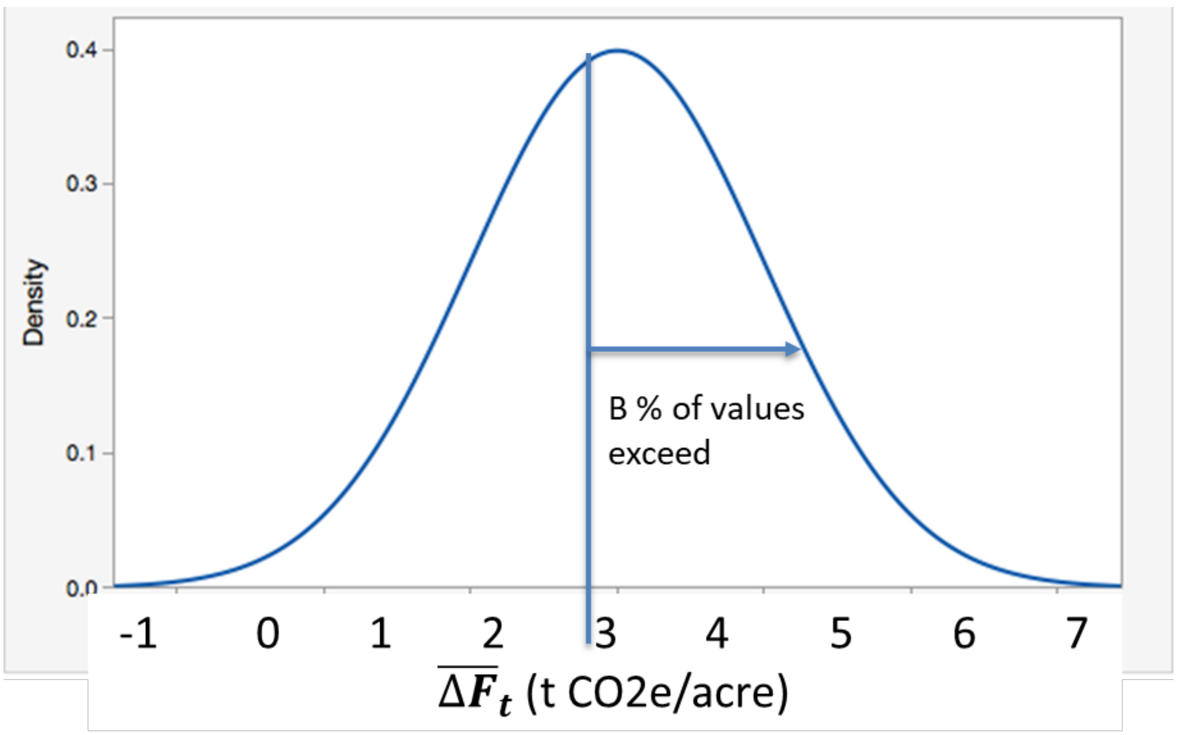

Figure 2: Probability of exceedance.
The estimated probability density function based on t-distribution for the sum of sources and sinks $\overline{\Delta F}_t$ for project minus baseline (ERRs). The value $\overline{\Delta F}_t$ for the probability of exceedance of B is value after uncertainty deduction.

The amount of sum of sources and sinks for the project is defined as:

Equation 85

$$UNCt = \frac{\overline{\Delta F}_{t,(100-B)/100}}{\overline{\Delta F}_t}$$

Where:

UNC_t	Uncertainty deduction in year t (expressed as the extent to which the half width of the 95% confidence interval, as a percentage of the mean, exceeds the threshold of A%); unitless number between 0 and 1
B	The probability of exceedance %, for case N1 B is set to be 55% while for case N3, B is set to 70%. Note, The Australian Carbon Credits Methodology uses 60% (Ministry for Industry, Energy and Emissions Reduction, Australia, 2021)

For analytical error propagation approach, the value of $\overline{\Delta F}_{t,(100-B)/100}$ is estimated from the pooled

variance as:

Equation 86

$$\overline{\Delta F}_{t,(100-B)/100} = \overline{\Delta F}_t + T_{(100-B)/100} * \sqrt{\sum\nolimits_{\bullet} s^2_{\Delta\bullet,t}}$$

Where:

$T_{(100-B)/100}$	Critical value of a student's t-distribution for significance level $\alpha = (100\% - B\%)/100\%$ and the degrees of freedom df appropriate for the design used (e.g., $df = n - 1$ for a simple random sample of n sample units).

For MC error propagation $\overline{\Delta F}_{t,(100-B)/100}$ is calculated using Equation 69, where $p = (100 - B)/100$ or using same approach as the analytical error propagation (as an approximation) and individual variances $s^2_{\Delta\bullet,t}$ are calculated using Equation 70 and the applied sample design.

Guidance to select Pathway A or B for uncertainty deduction

Figure 3 provides a decision tree showing the different cases and pathways for uncertainty calculation and application of uncertainty deduction threshold.

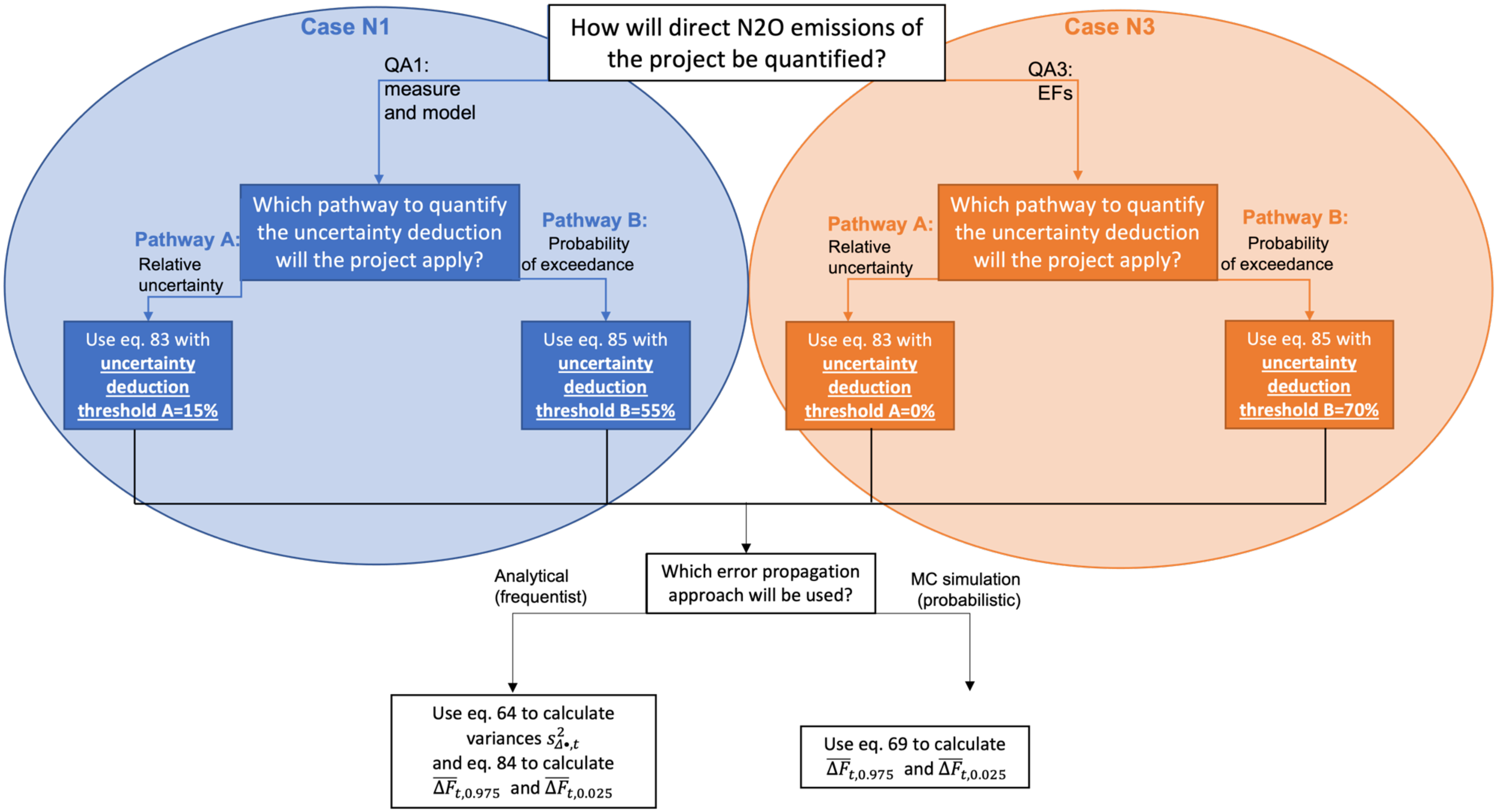

Figure 3: Decision tree for uncertainty deduction

Figure 4 gives the amount of deduction in absolute units, i.e. $UNCt * \overline{\Delta F}_t$, for some hypothetical situations for df=1000:

- Case N1
    - Pathway A: if the uncertainty relative to the mean ERRs is less than the threshold, there is no uncertainty deduction. The absolute deduction increases as the standard error increases, or the emission reduction decreases.
    - Pathway B always has an emission reduction. The absolute uncertainty deduction for Pathway B is unaffected by the value of the mean difference of sources and sinks between project minus baseline (ERRs).
- Case N3 has a greater deduction than case N1 but case N3 will invariably have a higher total uncertainty. Therefore, in practice, the uncertainty deduction is not necessarily less for case N1 than for case N3 for either Option A or Option B.

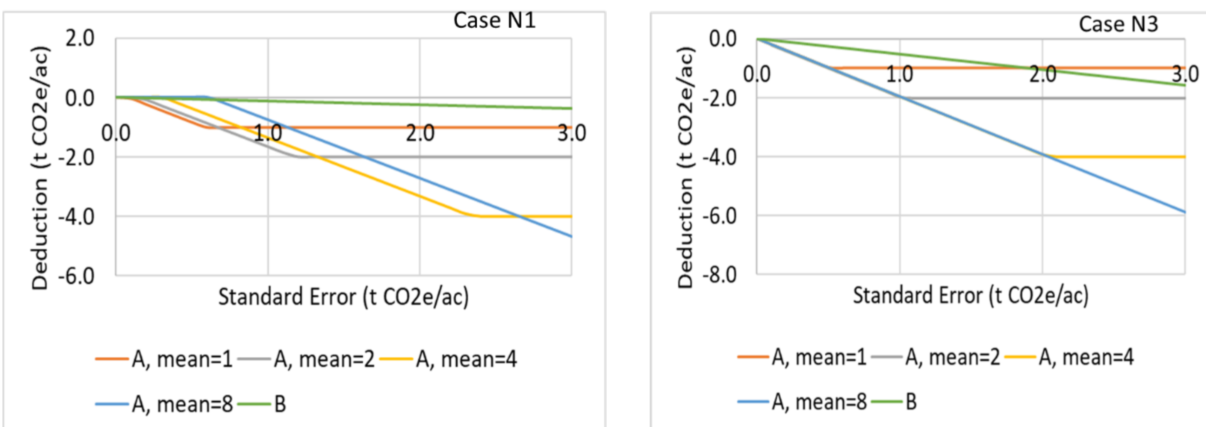

Figure **4**: Effect of the standard error on absolute uncertainty deduction
The effect of the mean sum of change in sources and sinks (t CO2e/ac) also shown for Pathway A (the mean does not affect the absolute deduction under Pathway B). This is done for case N1 when uncertainties for all relevant sources and sinks are assessed and included, and for case N3 when not all relevant uncertainties are included.

~~8.6~~8.7 Calculation of Verified Carbon Units

~~In order to~~To calculate the number of Verified Carbon Units (VCU) that may be issued, the project proponent must consider the number of buffer credits which must be deposited in the AFOLU pooled buffer account. The number of buffer credits ~~which~~ that must be deposited in the AFOLU pooled buffer account is calculated by multiplying the non-permanence risk rating[35] times the net change in carbon stocks only (see *VCS Methodology Requirements v4.0*, Section 3.8.5). The net change in carbon stocks is the sum of the net carbon dioxide removals resulting from the net increase in soil carbon, tree biomass and shrub biomass carbon pools (see equation xx, section 8.5). Therefore, the buffer deduction applies only to the estimated net GHG emissions removals in equation 53 below~~is based on the net change in carbon stocks~~.

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

Equation 87

$$VCU_t = E_{red,n,t} + (E_{rem,n,t} - Buffer_t)$$

VCU_t	Number of VCU in year *t*; t CO_2e
$E_{red,n,t}$	Estimated net GHG emissions reductions in year t; t CO_2e
$E_{rem,n,t}$	Estimated net GHG emissions removals in year t; t CO_2e
~~ER_t~~	~~Estimated net GHG emissions reductions and removals in year *t*; t CO_2e~~
$Buffer_t$	Number of buffer credits to be contributed to the AFOLU pooled buffer account in year *t*; t CO_2e

9 MONITORING

Where discretion exists in the selection of a value for a parameter, the principle of conservativeness must be applied (as described in Section 2.2.1 of the *VCS Standard, v4.0*).

[35] as determined by the *AFOLU Non-Permanence Risk Tool*

Box 1

Sources of information for all un-defined activity/management related model input variables (see Table 6 and Table 8~~Tables 4 and 7~~) and parameters $FFC_{bsl,j,i,t}$, $P_{bsl,l,i,t}$, $Days_{bsl,l,i,t}$, $M_{bsl,SF,i,t}$, $M_{bsl,OF,i,t}$, and $MB_{g,bsl,i,t}$, , relevant to the baseline, will follow requirements detailed below.

All *qualitative* information on agricultural management practices will be determined via consultation with, and substantiated with a signed attestation from, the farmer or landowner of the sample field during that period. Where the farmer or landowner is not able to provide qualitative information (e.g., a sample field is newly leased), the project proponent may follow the guidance for using the sources of quantitative information listed below.

The source of *quantitative* information on agricultural management practices, and any additional quantitative inputs where required by the model selected (Quantification Approach 1 and 2), or by the default (Quantification Approach 3), must be chosen with priority from higher to lower preference, as available, as follows, applying the principle of conservatism in all cases:

1. Historical management records supported by one or more forms of documented evidence pertaining to the selected sample field and period t = -1 to t = -5 (e.g., management logs, receipts or invoices, farm equipment specifications, logs or files containing machine and/or sensor data), or remote sensing (e.g., satellite imagery, manned aerial vehicle footage, drone imagery)~~-~~, where requisite information on agricultural management practices can be reliably determined with these methods (e.g., tillage status, crop type, irrigation).
2. Historical management plans supported by one or more forms of documented evidence pertaining to the selected sample field and period t = -1 to t = -5 (e.g., management plan, recommendations in writing solicited by the farmer or landowner from an agronomist). Where more than one value is documented in historical management plans (e.g., where a range of application rates are prescribed in written recommendations), the principle of conservatism will be applied, selecting the value that results in the lowest expected emissions (or highest rate of stock change) in the baseline scenario.
3. Determined via consultation ~~with, and~~with and substantiated with a signed attestation from the farmer or landowner of the sample field during that period ~~-~~– so long as the attested value does not deviate significantly from other evidence-supported values for similar fields (e.g., fertilizer data from adjacent fields with the same crop, adjacent years of the same field, government data of application rates in that area, or statement from a local extension agent regarding local application rates). The determination of the sufficiency of data is subject to the discretion of the validator. In circumstances where this requirement cannot be met, option ~~d~~ 4 must be followed.
4. Regional (sub-national) average values derived from agricultural census data or other sources from within the 20-year period preceding the project start date or the 10 most recent iterations of the dataset, whichever is more recent, referencing the relevant crop or ownership class where estimates have been disaggregated by those attributes, and substantiated with a signed attestation from the farmer or landowner

of the sample field during that period. Examples include the US Department of Agriculture (USDA) National Agricultural Statistics Service Quick Stats database and USDA Agricultural Resource Management Survey.

9.1 Data and Parameters Available at Validation

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

Data / Parameter	$Area_{an}$
Data unit	Hectares or acres
Description	Area of proposed project-level adoption of each activity
Equations	Equation 1
Source of data	Farm records and project activity commitments
Value applied	The proposed project-level adoption of $Activity_{an}$
Justification of choice of data or description of	See Section 7

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

Data / Parameter	EA_{an}
Data unit	Percent
Description	Adoption rate of the n largest most common proposed project activity in the region
Equations	Equation 1
Source of data	Publicly available information contained in agricultural census or other government (e.g., survey) data, peer-reviewed scientific literature, independent research data, or reports/assessments compiled by industry associations. If all of the above sources are unavailable, signed and date attestation statement from a qualified independent local expert.
Value applied	Conditional on data source
Justification of choice of data or description of measurement methods and procedures applied	See source of data above and Section 7
Purpose of Data	Common practice assessment
Comments	None

Data / Parameter	A_0
Data unit	Unit area
Description	Project area
Equations	Equation 36, Equation 37, Equation 71, Equation 72, Equation 73, Equation 74
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), or other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, clear landmarks or other intersection points.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{CO2,j}$
Data unit	t CO_2e/liter
Description	Emission factor for the type of fossil fuel *j* (gasoline or diesel) combusted
Equations	Equation 5
Source of data	Volume 2 Chapter 3 Table 3.3.1 (IPCC, 2019)
Value applied	For gasoline EF_{CO2}=0.002810 t CO_2e per liter. For diesel EF_{CO2}=0.002886 t CO_2e per liter
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	Assumes 4-stroke gasoline engine for gasoline combustion and default values for energy content of 47.1 GJ/t and 45.66 GJ/t for gasoline and diesel respectively (IEA, 2004).

Data / Parameter	$FFC_{bsl,j,i,t}$
Data unit	Liters

Description	Consumption of fossil fuel type *j* (gasoline or diesel) for sample unit *i* in year *t*
Equations	Equation 5
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	Fossil fuel consumption can be monitored, or the amount of fossil fuel combusted can be estimated using fuel efficiency (for example l/100 km, l/t-km, l/hour) of the vehicle and the appropriate unit of use for the selected fuel efficiency (for example km driven if efficiency is given in l/100 km).
Purpose of Data	Calculation of baseline
Comments	Peer-reviewed published data may be used to determine fuel efficiency. For example, fuel efficiency factors may be obtained from the (IPCC, 2019), Volume 2 Chapter 3

Data / Parameter	GWP_{CH4}
Data unit	t CO2e/t CH_4
Description	Global warming potential for CH_4
Equations	Equation 6, Equation 7, Equation 8, Equation 10
Source of data	IPCC F~~ourth~~ifth Assessment Report (IPCC, 2013)
Value applied	28~~5~~
Justification of choice of data or description of measurement methods and procedures applied	See source of data above. ~~Unless otherwise directed by the VCS Program,~~ VCS Standard v4.~~0~~1, Section 3.14.4 requires that CH_4 must be converted using the 100-year global warming potential derived from the IPCC ~~Fourth~~ Fifth Assessment Report for GHG emission reductions occurring on or after 1 January 2021.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{ent,l}$

Data unit	kg CH_4/(head * year)
Description	Enteric emission factor for livestock type *l*
Equations	Equation 7
Source of data	Peer-reviewed published data may be used. For example, suitable values may be selected from Volume 4 Chapter 10 Table 10.10 and Table 10.11 (IPCC, 2019)
Value applied	The emission factor is selected based on livestock type
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{CH4,md,l}$
Data unit	g CH4/(kg volatile solids)
Description	Emission factor for methane emissions from manure deposition for livestock type *l*
Equations	Equation 7
Source of data	Peer-reviewed published data may be used. For example, suitable values may be selected from the Volume 4 Chapter 10 Table 10.14 and Table 10.15 (IPCC, 2019)
Value applied	The emission factor is determined based on livestock type. Excluding livestock types listed in Table 10.15 in Chapter 10, Volume 4 (IPCC, 2019), a value of 0.6 is applied for all animals in both low and high productivity pasture, range, and paddock systems per Table 10.14 of the same chapter.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above

Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$VS_{rate,l}$
Data unit	kg volatile solids/(1000 kg animal mass * day)
Description	Default volatile solids excretion rate for livestock type *l*
Equations	Equation 9
Source of data	Peer-reviewed published data may be used. For example, suitable values may be selected from Volume 4, Chapter 10 Table 10.13a (IPCC, 2019)
Value applied	The volatile solids excretion rate is determined based on livestock type. Where agricultural systems are differentiated into low and high productivity systems in Table 10.13a in Chapter 10, Volume 4 (IPCC, 2019), the mean value is selected.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	CF_c
Data unit	Proportion of pre-fire fuel biomass consumed
Description	Combustion factor for agricultural residue type *c*
Equations	Equation 10, Equation 28
Source of data	~~2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 2 Table 2.6~~Volume 4, Chapter 2, Table 2.6 (IPCC, 2019)
Value applied	The combustion factor is selected based on the agricultural residue type burned

Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{c,CH4}$
Data unit	g CH_4/kg dry matter burnt
Description	Methane emission factor for the burning of agricultural residue type *c*
Equations	Equation 10
Source of data	Volume 4, Chapter 2, Table 2.5 (IPCC, 2019)
Value applied	The emission factor is selected based on the agricultural residue type burned
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	GWP_{N2O}
Data unit	t CO_2e / t N_2O
Description	Global warming potential for N_2O
Equations	Equation 11, Equation 14, Equation 19, Equation 20, Equation 23, Equation 26, Equation 27, Equation 28
Source of data	IPCC ~~Fourth~~ Fifth Assessment Report~~IPCC Fifthourth Assessment Report~~ (IPCC, 2013)

Value applied	2~~98~~65
Justification of choice of data or description of measurement methods and procedures applied	See source of data above. ~~Unless otherwise directed by the VCS Program,~~ VCS Standard v4.1, Section 3.14.4~~0~~ requires that N_2O must be converted using the 100-year global warming potential derived from the IPCC Fifth ~~Fourth~~ ~~Fifthourth~~ Assessment Report for GHG emission reductions occurring on or after 1 January 2021.
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{Ndirect}$
Data unit	t N2O-N/t N applied
Description	Emission factor for direct nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments and crop residues
Equations	Equation 14, Equation 20~~Equation 13, Equation 19Equation 13, Equation 19~~
Source of data	Volume 4 Chapter 11 Table 11.1 (IPCC, 2019)
Value applied	~~A value of 0.004 is applied for flooded rice fields. A value of 0.01 is applied for all other fields.~~A value of 0.01 is applied for N additions from synthetic fertilizers, organic amendments and crop residues, and N mineralized from mineral soil as a result of loss of SOC. Disaggregated values may be used as follow: • A value of 0.016 is applied for inputs of synthetic fertilizer and fertilizer mixtures that include both synthetic and organic forms of N~~.~~ in wet climates • A value of 0.006 is applied for other N input as organic amendments, animal manures, N in crop residues and mineralised N from SOC decomposition in wet climates • A value of 0.005 is applied to all N inputs in dry climates A value of 0.004 is applied for flooded rice fields. Disaggregated values may be used as follow: • A value of 0.006 is applied for continuous flooding.

	• A value of 0.005 is applied for single and multiple drainage A value of 0.004 is applied for manure from cattle (dairy, non-dairy and buffalo), poultry and pigs. Disaggregated values may be used as follow: • A value of 0.006 is applied for wet climates • A value of 0.002 is applied for dry climates. A value of 0.003 is applied for manure from sheep and '~~'~~other animals'~~'~~. When specific emission factors are available, a Tier 2 approach may be applied following the guidance in Chapter 11 Section 11.2.2.1 - Choice of Method and the good practice guidance in Chapter 2 Section 2.2.4 - Emission factors and direct measurement of emissions (IPCC, 2019), depending on, e.g., SOC content, soil texture, drainage, soil pH, N application rate per ~~fertiliser~~fertilizer type; ~~fertiliser~~fertilizer type, liquid or solid form of organic ~~fertiliser~~fertilizer; irrigation and type of crop with differences between legumes, non-leguminous arable crops, and grass.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	Emission factor applicable to N additions from mineral fertilizers, organic amendments and crop residues, and N mineralized from mineral soil as result of loss of soil carbon. Wet climates occur in temperate and boreal zones where the ratio of annual precipitation: potential evapotranspiration > 1, and tropical zones where annual precipitation > 1000 mm. Dry climates occur in temperate and boreal zones where the ratio of annual precipitation: potential evapotranspiration < 1, and tropical zones where annual precipitation < 1000 mm. 'Other animals' include goats, horses, mules, donkeys, camels, reindeer, and camelids.

Data / Parameter	*Frac_{GASF}*
Data unit	Dimensionless
Description	Fraction of all synthetic N added to soils that volatilizes as NH_3 and NO_x
Equations	Equation 18
Source of data	Volume 4, Chapter 11, Table 11.3 (IPCC, 2019)
Value applied	0.11
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$Frac_{GASM}$
Data unit	Dimensionless
Description	Fraction of all organic N added to soils and N in manure and urine deposited on soils that volatilizes as NH_3 and NO_x
Equations	Equation 18, Equation 26
Source of data	Volume 4, Chapter 11, Table 11.3 (IPCC, 2019)
Value applied	0.21
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	EF_{Nvolat}
Data unit	t N_2O-N /(t NH_3-N + NOx-N volatilized)
Description	Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces
Equations	Equation 18, Equation 26
Source of data	Volume 4, Chapter 11, Table 11.3 (IPCC, 2019)
Value applied	0.01
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$Frac_{LEACH}$
Data unit	Dimensionless
Description	Fraction of N added (synthetic or organic) to soils and N in manure and urine deposited on soils that is lost through leaching and runoff, in regions where leaching and runoff occurs
Equations	Equation 19, Equation 27
Source of data	Volume 4, Chapter 11, Table 11.3 (IPCC, 2019)
Value applied	For wet climates or in dry climate regions where irrigation (other than drip irrigation) is used, a value of 0.24 is applied. For dry climates, a value of zero is applied.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions

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

Data / Parameter	EF_{Nleach}
Data unit	t N_2O-N / t N leached and runoff
Description	Emission factor for nitrous oxide emissions from leaching and runoff
Equations	Equation 19, Equation 27
Source of data	Volume 4, Chapter 11, Table 11.3 (IPCC, 2019)
Value applied	0.011
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{N2O,md,l}$
Data unit	kg N_2O-N/kg N input
Description	Emission factor for nitrous oxide from manure and urine deposited on soils by livestock type *l*
Equations	Equation 23
Source of data	Volume 4, Chapter 11, Table 11.1 (IPCC, 2019)
Value applied	The emission factor for nitrous oxide from manure and urine deposited on soils is determined based on livestock type. For cattle, poultry, and pigs $EF_{N2O,md,l}$ = 0.004 kg N_2O-N/kg N input.

	For sheep and other animals $EF_{N2O,md,l}$=0.003 kg N_2O-N/kg N input.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	Nex_l
Data unit	kg N deposited/(t livestock mass * day)
Description	Nitrogen excretion of livestock type *l*
Equations	Equation 24
Source of data	Peer-reviewed published data may be used. For example, suitable values may be selected from Volume 4, Chapter 10, Table 10.19 (IPCC, 2019)
Value applied	The nitrogen excretion rate is determined based on livestock type. Where agricultural systems are differentiated into low and high productivity systems in Table 10.19 in Chapter 10, Volume 4, (IPCC, 2019), the mean value is selected.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$MS_{bsl,l,i,t}$
Data unit	Fraction of N deposited
Description	Fraction of nitrogen excretion of livestock type *l* that is deposited on the project area

Equations	Equation 24
Source of data	Data may be sourced according to the guidance in Box 1
Value applied	The fraction of nitrogen deposited on the project area is determined based on the amount of time spent grazing on the project area during year *t* for each livestock type. In the absence of data available according to Box 1 (or to conservatively reduce the effort of project development), a value of 1 may be applied with no additional support. This would conservatively assume that the livestock deposited 100% of their excreted N on the project area for the entirety of year *t*.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$N_{content,g}$
Data unit	t N/t dm
Description	Fraction of N in dry matter for N-fixing species *g*
Equations	Equation 21
Source of data	Volume 4, Chapter 11, Table 11.2 (IPCC, 2019)
Value applied	The fraction of N in dry matter is determined based on the N-fixing species type.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$EF_{c,N2O}$
Data unit	g N_2O/kg dry matter burnt
Description	Nitrous oxide emission factor for the burning of agricultural residue type *c*
Equations	Equation 28
Source of data	Volume 4, Chapter 2, Table 2.5 (IPCC, 2019)
Value applied	The emission factor is selected based on the agricultural residue type.
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$P_{bsl,l,i,t}$
Data unit	Head
Description	Population of grazing livestock in the baseline scenario of type *l* in sample unit *i* in year *t*
Equations	Equation 7, Equation 8, Equation 24
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$Days_{bsl,l,i,t}$
Data unit	Days
Description	Average grazing days per head in the baseline scenario inside sample unit *i* for each livestock type *l* in year *t*
Equations	Equation 7, Equation 8
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$MB_{bsl,c,i,t}$
Data unit	Kilograms
Description	Mass of agricultural residues of type *c* burned in the baseline scenario for sample unit *i* in year *t*
Equations	Equation 10, Equation 28 ~~Equation 9, Equation 27~~ ~~Equation 9, Equation 27~~
Source of data	Peer-reviewed published data may be used to estimate the aboveground biomass prior to burning.
Value applied	See source of data
Justification of choice of data or description of measurement methods and procedures applied	It is assumed that 100% of aboveground biomass is burned in both the baseline and with project cases.
Purpose of Data	Calculation of baseline emissions

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

Data / Parameter	$M_{bsl,SF,i,t}$
Data unit	t fertilizer
Description	Mass of baseline N containing synthetic fertilizer applied for sample unit *i* in year *t*
Equations	Equation 15
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$NC_{bsl,SF,i,t}$
Data unit	t N/t fertilizer
Description	N content of baseline synthetic fertilizer applied
Equations	Equation 15
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	N content is determined following fertilizer manufacturer's specifications

Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$M_{bsl,OF,i,t}$
Data unit	t fertilizer
Description	Mass of baseline N containing organic fertilizer applied for sample unit *i* in year *t*
Equations	Equation 16
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	Nex_l
Data unit	kg N/head/year
Description	Average annual nitrogen excretion per head of livestock type *l*
Equations	Equation 24
Source of data	Peer-reviewed published data may be used. For example, suitable values may be derived from Volume 4, Chapter 10, Section 10.5 (IPCC, 2019), applying a Tier 2 approach to equation 10.30. Where agricultural systems are differentiated into low and high productivity systems in Table 10.19 in Chapter 10, Volume 4 (IPCC, 2019), the mean value is selected. Typical animal mass values may be sourced from Annex 10A.1, Table 10A.5.

Value applied	
Justification of choice of data or description of measurement methods and procedures applied	See source of data above
Purpose of Data	Calculation of baseline and project emissions
Comments	None

Data / Parameter	$NC_{bsl,OF,i,t}$
Data unit	t N/t fertilizer
Description	N content of baseline organic fertilizer applied
Equations	Equation 16
Source of data	Peer-reviewed published data may be used. For example, default manure N contents may be selected from (Edmonds *et al.*, 2003) cited in (US EPA, 2011) or other regionally appropriate sources such as the European Environment Agency.
Value applied	See source of data
Justification of choice of data or description of measurement methods and procedures applied	See source of data
Purpose of Data	Calculation of baseline emissions
Comments	None

Data / Parameter	$MB_{g,bsl,i,t}$
Data unit	t dm
Description	Annual dry matter, including aboveground and below ground, of N-fixing species *g* returned to soils for sample unit *i* at time *t*
Equations	Equation 21

Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Calculation of baseline emissions
Comments	Mass of residues burned is a function of the amount of aboveground biomass, the removal of aboveground biomass, and whether or not remaining residues are burned.

Data / Parameter	$P_{bsl,p}$
Data unit	Productivity (e.g., kg) per hectare or acre
Description	Average productivity for product p during the historical baseline period
Equations	Equation 30, Equation 31
Source of data	See Box 1
Value applied	See Box 1
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Determination of baseline productivity for future market leakage analysis
Comments	None

Data / Parameter	$RP_{bsl,p}$
Data unit	Productivity (e.g., kg) per hectare or acre
Description	Average regional productivity for product p during the same years as the historical baseline period

Equations	Equation 31
Source of data	Secondary evidence sources of regional productivity (e.g., peer-reviewed science, industry associations, international databases, government databases)
Value applied	Conditional on data source
Justification of choice of data or description of measurement methods and procedures applied	See Box 1
Purpose of Data	Determination of baseline productivity ratio for future market leakage analysis
Comments	None

9.2 Data and Parameters Monitored

Data / Parameter:	AR
Data unit:	Percent
Description:	Weighted average adoption rate
Equations	Equation 1
Source of data:	Calculated for the project across the group or all activity instances
Description of measurement methods and procedures to be applied:	Not applicable
Frequency of monitoring/recording:	~~Annual~~WheneverA new instances are added~~nnual~~
QA/QC procedures to be applied:	See Section 7
Purpose of data:	Common practice assessment
Calculation method:	See Section 7

Comments:	None

Data / Parameter:	$Area_{an}$
Data unit:	Unit area (hectares or acres)
Description:	Area of proposed project-level adoption of each activity
Equations	Equation 1
Source of data:	Farm records and project activity commitments
Description of measurement methods and procedures to be applied:	The area is estimated prior to verification
Frequency of monitoring/recording:	~~Annual~~Whenever new instances are added
QA/QC procedures to be applied:	Delineation of the sample unit area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), or other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, clear landmarks or other intersection points.
Purpose of data:	Common practice assessment
Calculation method:	Not applicable (measured)
Comments:	None

Data / Parameter:	EA_{an}
Data unit:	Percent
Description:	Adoption rate of the n largest most common proposed project activity in the region
Equations	Equation 1
Source of data:	Publicly available information contained in agricultural census or other government (e.g., survey) data, peer-reviewed scientific

	literature, independent research data, or reports/assessments compiled by industry associations. If all of the above sources are unavailable, signed and date attestation statement from a qualified independent local expert.
Description of measurement methods and procedures to be applied:	Not applicable
Frequency of monitoring/recording:	Whenever new instances are added~~Annual~~
QA/QC procedures to be applied:	See Section 7
Purpose of data:	Common practice assessment
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	A_i
Data unit:	Unit area
Description:	Area of sample unit *i*
Equations	Equation 4, Equation 7, Equation 8, Equation 10, Equation 14, Equation 17, Equation 20, Equation 23, Equation 25, Equation 28, Equation 53, Equation 61, Equation 65, Equation 66, Equation 67
Source of data:	Determined in project area
Description of measurement methods and procedures to be applied:	The sample unit area is measured prior to verification
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years

QA/QC procedures to be applied:	Delineation of the sample unit area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), or other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, clear landmarks or other intersection points.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	*i*
Data unit:	Dimensionless
Description:	Sample unit; defined area that is selected for measurement and monitoring, such as a field or stratum; see also definition in section 3
Equations	Equation - Equation 27, Equation 33 - Equation 35, Equation 39 - Equation 42, Equation 44, Equation 45, Equation 48 - Equation 50 Equation ~~- Equation 27, Equation 33 - Equation 35, Equation 39 - Equation 42, Equation 44, Equation 45, Equation 48 - Equation 50~~
Source of data:	Determined in project area
Description of measurement methods and procedures to be applied:	The sample unit is determined prior to verification
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Delineation of the sample unit area may use a combination of GIS coverages, ground survey data, remote imagery (satellite or aerial photographs), or other appropriate data. Any imagery or GIS datasets used must be geo-registered referencing corner points, clear landmarks or other intersection points.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Not applicable

Comments:	None

Data / Parameter:	*j*
Data unit:	Dimensionless
Description:	Type of fossil fuel combusted
Equations	Equation 4, Equation 5~~Equation , Equation 4Equation , Equation 4~~
Source of data:	Determined in sample unit *i*
Description of measurement methods and procedures to be applied:	See Box 1. Fossil fuel type is determined prior to verification.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	*l*
Data unit:	Dimensionless
Description:	Type of livestock
Equations	Equation 7, Equation 8, Equation 9, Equation 23, Equation 24, Equation 26, Equation 27, Equation 29
Source of data:	Determined in sample unit *i*

Description of measurement methods and procedures to be applied:	See Box 1. ~~Vehicle~~ Livestock type is determined prior to verification.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	g
Data unit:	Dimensionless
Description:	Type of N-fixing species
Equations	Equation 21
Source of data:	Determined in sample 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 if less than five years
QA/QC procedures to be applied:	See Box 1.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	*c*
Data unit:	Dimensionless
Description:	Type of agricultural residue
Equations	Equation 10, Equation 28
Source of data:	Determined in sample unit *i*
Description of measurement methods and procedures to be applied:	See Box 1. Agricultural residue type is determined prior to verification.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	•
Data unit:	Dimensionless
Description:	Gas or pool
Equations	Equation 62, Equation 63, Equation 84, Equation 86
Source of data:	Determined in sample 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 if less than five years
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:	*SF*
Data unit:	Dimensionless
Description:	Type of synthetic N fertilizer
Equations	Equation 15
Source of data:	Determined in sample unit *i*
Description of measurement methods and procedures to be applied:	See Box 1. Synthetic fertilizer type is determined prior to verification.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	*OF*
Data unit:	Dimensionless

Description:	Type of organic N fertilizer
Equations	Equation 16
Source of data:	Determined in sample unit *i*
Description of measurement methods and procedures to be applied:	See Box 1. Organic fertilizer type is determined prior to verification.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1.
Purpose of data:	Calculation of baseline and project emissions
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	$f(SOC_{bsl,i,t-1})$
Data unit:	t CO_2e/unit area
Description:	Modeled soil organic carbon stocks pool in the baseline scenario for sample unit *i* at time *t*
Equations:	Equation 2
Source of data:	Modeled in the project area
Description of measurement methods and procedures to be applied:	Modeled soil organic carbon stocks in the baseline scenario are determined according to the equation: $$SOC_{bsl,i,t} = f_{SOC}(Var\ A_{bsl,i,t}, Var\ B_{bsl,i,t}, \dots)$$ Where:

	$SOC\_soil_{bsl,i,t}$ ~~=~~ Modeled soil organic carbon stocks pool in the baseline scenario for sample unit *i* at time *t* (t CO_2e/unit area) f_{SOC} ~~=~~ Model predicting carbon dioxide emissions from the soil organic carbon pool (t CO_2e/unit area) $Var\ A_{bsl,i,t}$ ~~=~~ Value of model input variable A in the project scenario for sample unit *i* at time t (units unspecified) $Var\ B_{bsl,i,t}$ ~~=~~ Value of model input variable B in the project scenario for sample 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:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QCs available from published handbooks, such as those published by FAO and available on the FAO Soils Portal[36], or from the IPCC GPG LULUCF 2003 is recommended.
Purpose of data:	Calculation of baseline emissions
Calculation method:	Not applicable
Comments:	The soil organic carbon stocks at time *t=0* are calculated based on directly measured soil organic carbon content and bulk density at *t=0* or (back-) modeled to *t =0* from measurements via conventional analytical laboratory methods, e.g., dry combustion, ~~collected~~ performed within +/-5 years of *t =0,* or determined for *t*=0 via emerging technologies (~~e.g., remote sensing~~INS, LIBS, MIR and Vis-NIR) with known uncertainty following the criteria in Appendix 4: Guidance on potential emerging technologies to measure SOC stocks, and must be used in both the baseline and with- project scenario for the length of the project.

[36] http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/

Data / Parameter:	$SOC_{bsl,i,t}$
Data unit:	t CO_2e/unit area
Description:	Areal-average soil organic carbon stocks in the baseline scenario for sample unit *i* in year *t*
Equations	Equation 38, Equation 39
~~Source of data:~~	Modeled ~~or measured~~ in the project area or measured in baseline control plots
~~Description of measurement methods and procedures to be applied:~~	See $fSOC_{bsl,i,t}$ above for modeled soil organic carbon stocks. Measured soil organic carbon must be determined from samples collected from sample plots located within each baseline control site. All organic material (e.g., living plants, crop residue) must be cleared from the soil surface prior to soil sampling. Soil must be sampled to a minimum depth of 30 cm. Soil organic carbon stocks must be estimated from measurements of both soil organic carbon content and bulk density taken at the same time, at the project start and re-measured every 5 years or~~f~~ less. Geographic locations of intended sampling points must be established prior to sampling. The location of both the intended sampling point and the actual sampling point must be recorded. If multiple cores are composited to create a single sample, these cores must all be from the same depth and be fully homogenized prior to subsampling. Soils must be shipped within 5 days of collection and should be kept cool until shipping. Acknowledging the wide range of valid monitoring approaches, and that relative efficiency and robustness are circumstance-specific, sampling, measurement and estimation procedures for measuring are not specified in the methodology and may be selected by project proponents based on capacity and appropriateness. Stratification may be employed to improve precision but is not required. Estimates generated must: • Be demonstrated to be unbiased and derived from representative sampling

- Accuracy of measurements and procedures is ensured through employment of quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in the monitoring plan)

Soil sampling should follow established best practices, such as those found in~~:~~

~~Cline, M.G. 1944. Principles of soil sampling. Soil Science. 58: 275 – 288.~~

~~Petersen, R.G., and Calvin, L.D. Sampling. In A. Klute, editor, 1986. Methods of Soil Analysis: Part 1—Physical and Mineralogical Methods. SSSA Book Ser. 5.1. SSSA, ASA, Madison, WI.~~ (Cline, 1944; Petersen and Calvin, 1986; Gruijter *et al.*, 2006; Soil Science Division Staff, 2017; FAO, 2019; Smith *et al.*, 2020).

When measuring SOC via conventional analytical laboratory methods, the use of dry combustion is recommended over other techniques. Determination of percent soil organic carbon should follow established laboratory procedures, such as those found in~~:~~

~~Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. p. 539–580. In A.L. Page et al. (ed.) Methods of soil Analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.~~

~~Schumacher, B. A. Methods for the determination of total organic carbon (TOC) in soils and sediments. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-02/069 (NTIS PB2003-100822), 2002, or other regionally appropriate sources such as the European Environment Agency.~~ (Nelson and Sommers, 1982; ISO, 1995; Schumacher, 2002).

Standardization of soil measurement methods is a globally recognized need (for example: ISRIC World Soil Information Service (WoSIS)- see Ribeiro et al. (2018)). Measurement procedures for soil organic carbon and bulk density should be thoroughly described, including all sample handling, preparation for analysis, and analysis techniques.

	~~Ribeiro, E., N. H. Batjes and A. van Oostrum. 2018. World Soil Information Service (WoSIS) - Towards the standardization and harmonization of world soil data. ISRIC Report 2018/01, 2018, Wageningen, Netherlands~~
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See $fSOC_{bsl,i,t}$ above.
Purpose of data:	Calculation of baseline emissions
Calculation method:	Not applicable
Comments:	The soil organic carbon stocks at time *t=0* are calculated based on directly measured soil organic carbon content and bulk density at *t=0* or (back-) modeled to *t =0* from measurements collected within +/-5 years of *t =0,* or determined for *t*=0 via emerging technologies (e.g., ~~remote sensing~~proximal sensing) with known uncertainty, and must be used in both the baseline and with- project scenario for the length of the project. Note that bulk density measurements are not necessarily required to determine SOC stock changes on an ESM basis. Soil organic carbon stocks in the baseline scenario for sample unit *i* must be reported every 5 years or less.

Data / Parameter:	$SOC_{bsl,i,t-1}$
Data unit:	t CO_2e/unit area
Description:	Areal-average soil organic carbon stocks in the baseline scenario for sample unit *i* in year *t-1*
Equations	Equation 38, Equation 39
Source of data:	Modeled or measured in the project area
Description of measurement methods and procedures to be applied:	See ~~f~~$SOC_{bsl,i,t}$ above.

Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See $ƒSOC_{bsl,i,t}$ above.
Purpose of data:	Calculation of baseline emissions
Calculation method:	Not applicable
~~Comments:~~	~~The soil organic carbon stocks at time *t=0* are~~ calculated based on ~~directly measured~~ soil organic carbon content and bulk density ~~at *t=0* or (back-) modeled to *t =0* from measurements~~ via conventional analytical laboratory methods, e.g., dry combustion, ~~collected~~ performed ~~within +/-5 years of *t =0*, or determined for *t*=0 via emerging technologies (e.g., remote sensing~~INS, LIBS, MIR and Vis-NIR~~) with known uncertainty~~ following the criteria in ~~Appendix 4~~Appendix 3~~, and must be used in both the baseline and with- project scenario for the length of the project.~~ ~~Soil organic carbon stocks in the baseline scenario for sample unit *i* must be reported every 5 years or less.~~

~~Data / Parameter:~~	~~$SOC_{bsl,i,t-1}$~~
~~Data unit:~~	~~t CO_2e/unit area~~
~~Description:~~	~~Areal-average soil organic carbon stocks in the baseline scenario for sample unit *i* in year *t-1*~~
~~Equations~~	~~Equation 33, Equation 34~~
~~Source of data:~~	~~Modeled or measured in the project area~~
~~Description of measurement methods and procedures to be applied:~~	~~See $ƒSOC_{bsl,i,t}$ above.~~
~~Frequency of monitoring/recording:~~	~~Monitoring must be conducted at least every five years, or prior to each verification event if less than five years~~
~~QA/QC procedures to be applied:~~	~~See $ƒSOC_{bsl,i,t}$ above~~ and $SOC_{wp,i,t}$ below for sampling and measurement guidance~~.~~

~~Purpose of data:~~	~~Calculation of baseline emissions~~
~~Calculation method:~~	~~Not applicable~~
Comments:	None

Data / Parameter:	$SOC_{wp,i,t}$
Data unit:	t CO_2e/unit area
Description:	Areal-average soil organic carbon stocks in the project scenario for sample unit *i* in year *t*
Equations	Equation 38, Equation 39
Source of data:	Modeled or measured in the project area
Description of measurement methods and procedures to be applied:	Modeled soil organic carbon stocks in the project scenario are determined according to the equation: $$fSOC_{wp,i,t} = f_{SOC}(Var\ A_{wp,i,t}, Var\ B_{wp,i,t}, \ldots)$$ Where: $fSOC_{wp,i,t}$ = Modeled carbon dioxide emissions from soil organic carbon pool in the baseline scenario for sample unit *i* at time *t* (t CO_2e/unit area) f_{SOC} = Model predicting carbon dioxide emissions from the soil organic carbon pool (t CO_2e/unit area) $Var\ A_{wp,i,t}$ = Value of model input variable A in the project scenario for sample unit *i* at time t (units unspecified) $Var\ B_{wp,i,t}$ = Value of model input variable B in the project scenario for sample 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.

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

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

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

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

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

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

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

	specific, sampling, measurement and estimation procedures for measuring are not specified in the methodology and may be selected by project proponents based on capacity and appropriateness. Stratification may be employed to improve precision but is not required. Estimates generated must: • Be demonstrated to be unbiased and derived from representative sampling • Accuracy of measurements and procedures is ensured through employment of quality assurance/quality control (QA/QC) procedures (to be determined by the project proponent and outlined in the monitoring plan) Soil sampling should follow established best practices, such as those found in (Cline, 1944; Petersen and Calvin, 1986; Gruijter *et al.*, 2006; Soil Science Division Staff, 2017; FAO, 2019; Smith *et al.*, 2020). When measuring SOC via conventional analytical laboratory methods, the use of dry combustion is recommended over other techniques. Determination of percent soil organic carbon should follow established laboratory procedures, such as those found in~~:~~ (Nelson and Sommers, 1982; ISO, 1995; Schumacher, 2002). Standardization of soil measurement methods is a globally recognized need (for example: ISRIC World Soil Information Service (WoSIS) (Ribeiro, Batjes and van Oostrum, 2018)). Measurement procedures for soil organic carbon and bulk density should be thoroughly described, including all sample handling, preparation for analysis, and analysis techniques.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QCs available from published handbooks, such as those published by FAO and available on the FAO Soils Portal[37] or from the IPCC GPG LULUCF 2003 is recommended.
Purpose of data:	Calculation of project emissions

[37] http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/

Calculation method:	Not applicable
Comments:	The soil organic carbon stocks at time *t=0* are calculated based on directly measured soil organic carbon content and bulk density at *t=0* or (back-) modeled to *t =0* from measurements collected within +/-5 years of *t=0,* or determined for *t*=0 via emerging technologies (~~e.g., remote sensing~~INS, LIBS, MIR and Vis-NIR) with known uncertainty following the criteria in ~~Appendix 4~~Appendix 4, and must be used in both the baseline and with-project scenario for the length of the project. Note that bulk density measurements are not necessarily required to determine SOC stock changes on an ESM basis. Soil organic carbon stocks in the project scenario for sample unit *i* must be reported every 5 years or less. Where re-measurement of soil organic carbon stocks indicates lower stocks than previously estimated by modeling, procedures in the most current version of the VCS Registration and Issuance Process for loss or reversal events are followed, as appropriate.

Data / Parameter:	$SOC_{wp,i,t-1}$
Data unit:	t CO_2e/unit area
Description:	Areal-average soil organic carbon stocks in the project scenario for sample unit *i* in year *t-1*
Equations	Equation 38, Equation 39
Source of data:	Modeled or measured in the project area
Description of measurement methods and procedures to be applied:	See $SOC_{wp,i,t}$ above.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See $SOC_{wp,i,t}$ above.
Purpose of data:	Calculation of project emissions

Calculation method:	Not applicable
Comments:	None

Data / Parameter:	$M_{n,dl,SOC}$
Data unit:	g
Description:	Soil mass in one sample depth layer
Equations	Equation 3
Source of data:	Measured after soil sampling in the project area
Description of measurement methods and procedures to be applied:	See $SOC_{wp,i,t}$ above
Frequency of monitoring/recording:	Monitoring of SOC stock changes must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Soil sampling should follow established best practices, such as those found in Gruijter *et al.*, 2006; Soil Science Division Staff, 2017; FAO, 2019; Smith *et al.*, 2020. Soil mass shall not include the mass of soil >2mm, i.e. gravel/stones and plant material. Beem-Miller, *et al*. (2016) provides a useful approach to ensuring high-quality sampling in rocky agricultural soils.
Purpose of data:	Calculation of project emissions
Calculation method:	A detailed description of SOC stock calculations with multiple soil depth increments along with spreadsheets or R scripts to standardize and facilitate calculations are provided in Wendt and Hauser, 2013 and von Haden, Yang and DeLucia, 2020.
Comments:	None

Data / Parameter:	D
Data unit:	mm
Description:	Inside diameter of probe or auger
Equations	Equation 3
Source of data:	Measured as part of project monitoring
Description of measurement methods and procedures to be applied:	n.a.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Soil sampling should follow established best practices, such as those found in Gruijter *et al.*, 2006; Soil Science Division Staff, 2017; FAO, 2019; Smith *et al.*, 2020.
Purpose of data:	Calculation of project emissions
Calculation method:	n.a.
Comments:	None

Data / Parameter:	N
Data unit:	unitless
Description:	Number of cores sampled
Equations	Equation 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 9.3.1)

Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QCs available from published handbooks, such as those published by FAO and available on the FAO Soils Portal[38] or from the IPCC GPG LULUCF 2003 is recommended.
Purpose of data:	Calculation of project emissions
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	$OC_{n,dl}$
Data unit:	g/kg
Description:	Organic carbon concentration in each sample
Equations	Equation 3
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: Guidance on potential emerging technologies to measure SOC stocks.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Determination of percent soil organic carbon should follow established laboratory standard operation procedures, such as those found in: (Nelson and Sommers, 1982; ISO, 1995; Schumacher, 2002).

[38] http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/

Purpose of data:	Calculation of project emissions
Calculation method:	n.a.
Comments:	None

Data / Parameter:	$fCH4soil_{bsl,i,t}$
Data unit:	t CH4/unit area
Description:	Modeled methane emissions from the soil organic carbon pool in the baseline scenario for sample unit *i* at time *t*
Equations:	Equation 6
Source of data:	Modeled in the project area
Value applied:	
Description of measurement methods and procedures to be applied:	Modeled soil organic carbon stocks in the baseline scenario are determined according to the equation: $$fCH4soil_{bsl,i,t} = f_{CH4soil}(Var\ A_{bsl,i,t}, Var\ B_{bsl,i,t}, \ldots)$$ Where: $fCH4soil_{bsl,i,t}$ = Modeled methane emissions from the soil organic carbon pool in the baseline scenario for sample unit *i* at time *t* (t CH_4/unit area) $f_{CH4soil}$ = Model predicting methane emissions from the soil organic carbon pool $Var\ A_{bsl,i,t}$ = Value of model input variable A in the project scenario for sample unit *i* at time *t* (units unspecified) $Var\ B_{bsl,i,t}$ = Value of model input variable B in the project scenario for sample 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:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QCs available from published hand-books, such as those published by FAO and available on the FAO Soils Portal[39], or from the IPCC GPG LULUCF 2003 (IPCC, 2003) is recommended.
Purpose of data:	Calculation of baseline emissions
Calculation method:	Not applicable
Comments:	The soil organic carbon stocks at time *t=0* are directly measured at *t=0* or (back-) modeled to *t =0* from measurements collected within +/-5 years of *t =0*, or determined for *t*=0 via emerging technologies (~~e.g., remote sensing~~INS, LIBS, MIR and Vis-NIR) with known uncertainty following the criteria in Appendix 4: Guidance on potential emerging technologies to measure SOC stocks, and must be used in both the baseline and with- project scenario for the length of the project.

Data / Parameter:	$fN2Osoil_{bsl,i,t}$
Data unit:	t N2O/unit area
Description:	Modeled nitrous oxide emissions from soil in the baseline scenario for sample unit *i* at time *t*
Equations:	Equation 11
Source of data:	Modeled in the project area
Value applied:	

[39] http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/

Description of measurement methods and procedures to be applied:	Modeled nitrous oxide emissions from soil in the baseline scenario are determined according to the equation: $$fN2Osoil_{bsl,i,t} = f_{N2Osoil}(Var\ A_{bsl,i,t}, Var\ B_{bsl,i,t}, \ldots)$$ Where: $fN2Osoil_{bsl,i,t}$ = Modeled nitrous oxide emissions from soil in the baseline scenario for sample unit *i* at time *t* (t CH_4/unit area) $f_{N2Osoil}$ = Model predicting methane emissions from the soil organic carbon pool $Var\ A_{bsl,i,t}$ = Value of model input variable A in the project scenario for sample unit *i* at time *t* (units unspecified) $Var\ B_{bsl,i,t}$ = Value of model input variable B in the project scenario for sample 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:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Standard QA/QC procedures for soil inventory including field data collection and data management must be applied. Use or adaptation of QA/QCs available from published hand-books, such as those published by FAO and available on the FAO Soils Portal[40], or from the IPCC GPG LULUCF 2003 is recommended.~~(IPCC, 2003) is recommended.~~
Purpose of data:	Calculation of baseline emissions
Calculation method:	Not applicable
Comments:	The soil organic carbon stocks at time *t=0* are directly measured at *t=0* or (back-) modeled to *t =0* from

[40] http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/
~~http://www.fao.org/soils-portal/soil-survey/sampling-and-laboratory-techniques/en/~~

	measurements collected within +/-5 years of *t* =0*,* or determined for *t*=0 via emerging technologies (~~e.g., remote sensing~~INS, LIBS, MIR and Vis-NIR) with known uncertainty following the criteria in Appendix 4: Guidance on potential emerging technologies to measure SOC stocks, and must be used in both the baseline and with- project scenario for the length of the project.

~~Data / Parameter:~~	~~$\Delta SOC_{bsl,i,t}$~~
~~Data unit:~~	~~t CO_2e/unit area~~
~~Description:~~	~~Estimated temporal change in carbon stocks in the soil organic carbon pool in the baseline scenario for sample field *i* in year *t* based on approved performance benchmark expressed in terms of change in soil organic carbon stocks per unit area per unit time~~
~~Equations~~	~~Equation 34Equation 34~~
~~Source of data:~~	~~Approved performance benchmark~~
~~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 if less than five years~~
~~QA/QC procedures to be applied:~~	
~~Purpose of data:~~	~~Calculation of emission reductions~~
~~Calculation method:~~	~~A performance benchmark-derived rate of change in soil organic carbon stocks per unit area is calculated to estimate carbon stocks in the soil organic carbon pool in the baseline scenario for sample field *i* in year *t*.~~
~~Comments:~~	~~Performance benchmarks for demonstration of the crediting baseline may be established through a revision to this methodology following requirements in the most current versions of the VCS Standard and VCS Methodology Requirements.~~

Data / Parameter:	$\bar{\Delta}_{\bullet,t}$ and $\bar{\bullet}_t$
Data unit:	t CO_2e/unit area
Description:	Average emission reductions from pool or source •, or stock of pool •, in year *t*
Equations	Equation 62, Equation 63, Equation 84, Equation 86
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 if less than five years
QA/QC procedures to be applied:	
Purpose of data:	Calculation of emission reductions
Calculation method:	The average emission reductions from pool or source •, or stock of pool •, at time *t* are estimated using unbiased statistical approaches, such as from~~:~~ (Cochran, 1977)~~:~~. ~~Cochran, W.G., 1977. Sampling Techniques: 3d Ed. New York: Wiley.~~ It is understood that application of this methodology may employ sample units of unequal sizes, which would necessitate proper weighting of samples in deriving averages. A range of sample designs (e.g., simple random samples, stratified samples, variable probability samples, multi-stage samples) may be employed.
Comments:	None

Data / Parameter:	$\Delta C_{TREE,bsl,i,t}$
Data unit:	t CO_2e/unit area

Description:	Change in carbon stocks in trees in the baseline
Equations	See Section 8.2.2 and Equation 41
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 if less than five years
QA/QC procedures to be applied:	See description of measurement methods and procedures to be applied
Purpose of data:	Calculation of baseline emissions
Calculation method:	See description of measurement methods and procedures to be applied
Comments:	None

Data / Parameter:	$\Delta C_{SHRUB,bsli,t}$
Data unit:	t CO_2e/unit area
Description:	Change in carbon stocks in shrubs in the baseline
Equations	See Section 8.2.2 and Equation 42
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 if less than five years
QA/QC procedures to be applied:	See description of measurement methods and procedures to be applied
Purpose of data:	Calculation of baseline emissions
Calculation method:	See description of measurement methods and procedures to be applied
Comments:	None

Data / Parameter:	$\Delta C_{TREE,wp,i,t}$
Data unit:	t CO_2e/unit area
Description:	Change in carbon stocks in trees in the project
Equations	See Section 8.2.2 and Equation 41
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 if less than five years
QA/QC procedures to be applied:	See description of measurement methods and procedures to be applied
Purpose of data:	Calculation of project emissions
Calculation method:	See description of measurement methods and procedures to be applied
Comments:	None

Data / Parameter:	$\Delta C_{SHRUB,wp,i,t}$
Data unit:	t CO_2e/unit area
Description:	Change in carbon stocks in shrubs in the project
Equations	See Section 8.2.2 and Equation 42
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 if less than five years
QA/QC procedures to be applied:	See description of measurement methods and procedures to be applied
Purpose of data:	Calculation of project emissions
Calculation method:	See description of measurement methods and procedures to be applied
Comments:	None

Data / Parameter:	$FFC_{wp,j,i,t}$
Data unit:	Liters
Description:	Consumption of fossil fuel type *j* in the project for sample unit *i* in year *t*
Equations	Equation 5
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	Fossil fuel consumption can be monitored, or the amount of fossil fuel combusted can be estimated using fuel efficiency (for example l/100 km, l/t-km, l/hour) of the vehicle type and the

	appropriate unit of use for the selected fuel efficiency (for example km driven if efficiency is given in l/100 km).
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Guidance provided in IPCC, 2003 Chapter 5 or IPCC, 2000 Chapter 8 must be applied
Purpose of data:	Calculation of project emissions
Calculation method:	Fuel efficiency factors can be obtained from the Volume 2, Chapter 3 (IPCC, 2019)
Comments:	For all equations, the subscript *bsl* must be substituted by *wps* to make clear that the relevant values are being quantified for the project scenario.

Data / Parameter:	$P_{wp,l,i,t}$
Data unit:	Head
Description:	Population of grazing livestock in the project scenario of type *l* in sample unit *i* in year *t*
Equations	Equation 7, Equation 8, Equation 24
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	Record numbers of grazing livestock by type.
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Information will be monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the sample unit. Any quantitative information (e.g., discrete or continuous numeric variables) on agricultural management practices must be supported by one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts or invoices, farm equipment specifications).

Purpose of data:	Calculation of project emissions
Calculation method:	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:	$Days_{wp,l,i,t}$
Data unit:	Days
Description:	Average grazing days per head in the project scenario inside sample unit *i* for each livestock type *l* in year *t*
Equations	Equation 7, Equation 8, Equation 24
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	Record livestock grazing days by type
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Information will be monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the sample unit. Any quantitative information (e.g., discrete or continuous numeric variables) on agricultural management practices must be supported by one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts or invoices, farm equipment specifications).
Purpose of data:	Calculation of project emissions
Calculation method:	Not applicable
Comments:	For all equations, the subscript *bsl* must be substituted by *wps* to make clear that the relevant values are being quantified for the project scenario

Data / Parameter:	$MB_{wp,c,i,t}$
Data unit:	Kilograms
Description:	Mass of agricultural residues of type *c* burned in the project for sample unit *i* in year *t*
Equations	Equation 10, Equation 28 ~~Equation 9, Equation 27~~ ~~Equation 9, Equation 27~~
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	Estimate the aboveground biomass of grassland before burning for at least three plots (1m*1m). The difference of the aboveground biomass is the aboveground biomass burnt
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Guidance provided in (IPCC, 2003) ~~IPCC, 2003~~ Chapter 5 or (IPCC, 2000)~~IPCC, 2000~~ Chapter 8 must be applied.
Purpose of data:	Calculation project emissions
Calculation method:	Not applicable
Comments:	For all equations, the subscript *bsl* must be substituted by *wps* to make clear that the relevant values are being quantified for the project scenario

Data / Parameter:	$M_{wp,SF,i,t}$
Data unit:	t fertilizer
Description:	Mass of N containing synthetic fertilizer applied in the project for sample unit *i* in year *t*
Equations	Equation 15
Source of data:	See Box 1

Description of measurement methods and procedures to be applied:	See Box 1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Information will be monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the sample unit. Any quantitative information (e.g., discrete or continuous numeric variables) on agricultural management practices must be supported by one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts or invoices, farm equipment specifications).
Purpose of data:	Calculation project emissions
Calculation method:	Not applicable
Comments:	For all equations, the subscript *bsl* must be substituted by *wps* to make clear that the relevant values are being quantified for the project scenario

Data / Parameter:	$M_{wp,OF,i,t}$
Data unit:	t fertilizer
Description:	Mass of N containing organic fertilizer applied in the project for sample unit *i* in year *t*
Equations	Equation 16
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	See Box 1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years

QA/QC procedures to be applied:	Information will be monitored via direct consultation with, and substantiated with a written attestation from, the farmer or landowner of the sample unit. Any quantitative information (e.g., discrete or continuous numeric variables) on agricultural management practices must be supported by one or more forms of documented evidence pertaining to the selected sample unit and relevant monitoring period (e.g., management logs, receipts or invoices, farm equipment specifications).
Purpose of data:	Calculation project emissions
Calculation method:	Not applicable
Comments:	For all equations, the subscript *bsl* must be substituted by *wps* to make clear that the relevant values are being quantified for the project scenario

Data / Parameter:	$W_{wp,l,i,t}$
Data unit:	kg animal mass/head
Description:	Average weight in the project scenario of livestock type *l* for sample unit *i* in year *t*
Equations	Equation 9
Source of data:	Peer-reviewed published data or expert judgement may be used
Description of measurement methods and procedures to be applied:	See source above
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	The project proponent must justify why the values selected for these parameters results in emission reductions that are conservative
Purpose of data:	Calculation of project emissions
Calculation method:	Not applicable

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

Data / Parameter:	$MB_{g,wp,i,t}$
Data unit:	t dm
Description:	Annual dry matter, including aboveground and below ground, of N-fixing species *g* returned to soils for sample unit *i* in year *t*
Equations	Equation 21
Source of data:	Aboveground and belowground dry matter in N-fixing species *g* returned to soil may be directly measured, or peer-reviewed published data may be used.
Description of measurement methods and procedures to be applied:	See source above
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	
Purpose of data:	Calculation of project emissions
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	$LE_{,t}$
Data unit:	tCO2e
Description:	Leakage in year *t*;
Equations	Equation 29, Equation 36, Equation 37

Source of data:	Not applicable
Description of measurement methods and procedures to be applied:	Leakage is equal to zero per the applicability conditions and Section 8.4 of this methodology
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	Not applicable
Purpose of data:	Calculation of project emissions
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	$M\_manure_{prj,l,t}$
Data unit:	tonnes
Description:	Project manure applied as fertilizer on the project area from livestock type *l* in year *t*
Equations	Equation 29
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	See Box 1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Calculation of project emissions from leakage

Calculation method:	Not applicable
Comments:	None

Data / Parameter:	$CC_{prj,l,t}$
Data unit:	fraction
Description:	Carbon content of manure applied as fertilizer on the project area from livestock type l in year *t*
Equations	Equation 29
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	See Box 1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Calculation of project emissions from leakage
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	ΔP
Data unit:	Percent
Description:	Change in productivity
Equations	Equation 30
Source of data:	Calculated (not applicable)

Description of measurement methods and procedures to be applied:	Not applicable
Frequency of monitoring/recording:	Every 10 years
QA/QC procedures to be applied:	Not applicable
Purpose of data:	Determination of change in crop/livestock productivity for leakage analysis
Calculation method:	See Section 8.4.3
Comments:	None

Data / Parameter:	$P_{wp,p}$
Data unit:	Productivity (e.g., kg) per hectare or acre
Description:	Average productivity for product p during the project period
Equations	Equation 30, Equation 31
Source of data:	Farm productivity (e.g., yield) records
Description of measurement methods and procedures to be applied:	Measured using locally available technologies (e.g., mobile weighing devices, commercial scales, storage volume measurements, fixed scales, weigh scale tickets, etc.)
Frequency of monitoring/recording:	Each growing season
QA/QC procedures to be applied:	See Box 1
Purpose of data:	Determination of project productivity for market leakage analysis
Calculation method:	Not applicable (measured)
Comments:	None

Data / Parameter:	p
Data unit:	Categorical variable
Description:	Crop/livestock product
Equations	Equation 30, Equation 31
Source of data:	See Box 1
Description of measurement methods and procedures to be applied:	Not applicable
Frequency of monitoring/recording:	Each growing season
QA/QC procedures to be applied:	Not applicable
Purpose of data:	Identification of crop/livestock product for market leakage analysis
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	ΔPR
Data unit:	Percent
Description:	Change in productivity ratio
Equations	Equation 31
Source of data:	Calculated (not applicable)
Description of measurement methods and procedures to be applied:	Not applicable

Frequency of monitoring/recording:	Every 10 years
QA/QC procedures to be applied:	Not applicable
Purpose of data:	Determination of change in crop/livestock productivity for leakage analysis
Calculation method:	See Section 8.4.3
Comments:	None

Data / Parameter:	$RP_{wp,p}$
Data unit:	Unitless
Description:	Average regional productivity for product p during the same years as the project period
Equations	Equation 31
Source of data:	Regional productivity data from government (e.g., USDA Actual Production History data), industry, published, academic or international organization (e.g., FAO) sources.
Description of measurement methods and procedures to be applied:	Not applicable
Frequency of monitoring/recording:	Every 10 years
QA/QC procedures to be applied:	Not applicable
Purpose of data:	Determination of project productivity ratio for market leakage analysis
Calculation method:	Not applicable
Comments:	None

Data / Parameter:	*Buffer,t*
Data unit:	tCO2e
Description:	Number of buffer credits to be contributed to the AFOLU pooled buffer account in year *t*
Equations	Equation 87
Source of data:	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the latest version of the *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 if less than five years
QA/QC procedures to be applied:	The number of buffer credits to be contributed to the AFOLU pooled buffer account must be determined by applying the latest version of the *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 latest version of the *VCS AFOLU Non-Permanence Risk Tool*
Comments:	None

Data / Parameter:	MDD
Data unit:	t CO_2e/unit area
Description:	Minimum detectable difference of SOC stocks between two points in time
Equations	Equation 88, Equation 89
Source of data:	Estimation of the smallest difference in SOC stock between two monitoring events that can be detected as statistically significant

Description of measurement methods and procedures to be applied:	See section 9.3.1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See section 9.3.1 and further guidance in FAO, 2019
Purpose of data:	Development of sampling strategy for baseline setting or measurements for monitoring
Calculation method:	See section 9.3.1
Comments:	Calculation of the number of required samples to detect a minimum difference is optional for projects

Data / Parameter:	S
Data unit:	Dimensionless
Description:	standard deviation of the difference in SOC stocks between t_0 and t_1
Equations	Equation 88, Equation 89
Source of data:	Estimation of the smallest difference in SOC stock between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied:	See section 9.3.1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See section 9.3.1 and further guidance in FAO, 2019
Purpose of data:	Development of sampling strategy for baseline setting or measurements for monitoring

Calculation method:	See section 9.3.1
Comments:	Calculation of the number of required samples to detect a minimum difference is optional for projects

Data / Parameter:	n
Data unit:	Dimensionless
Description:	Number of samples required to detect a minimum difference
Equations	Equation 88, Equation 89
Source of data:	Estimation of the smallest difference in SOC stock between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied:	See section 9.3.1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See section 9.3.1 and further guidance in FAO, 2019
Purpose of data:	Development of sampling strategy for baseline setting or measurements for monitoring
Calculation method:	See section 9.3.1
Comments:	Calculation of the number of required samples to detect a minimum difference is optional for projects

Data / Parameter:	ν
Data unit:	Dimensionless
Description:	Degrees of freedom for the relevant t-distribution
Equations	Equation 88, Equation 89

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

Data / Parameter:	t
Data unit:	Dimensionless
Description:	Values of the t-distribution given a certain power level (1-β) and α level (i.e., significance level)
Equations	Equation 88, Equation 89
Source of data:	Estimation of the smallest difference in SOC stock between two monitoring events that can be detected as statistically significant
Description of measurement methods and procedures to be applied:	See section 9.3.1
Frequency of monitoring/recording:	Monitoring must be conducted at least every five years, or prior to each verification event if less than five years
QA/QC procedures to be applied:	See section 9.3.1 and further guidance in (FAO, 2019)

Purpose of data:	Development of sampling strategy for baseline setting or measurements for monitoring
Calculation method:	See section 9.3.1
Comments:	Calculation of the number of required samples to detect a minimum difference is optional for projects

9.3 Description of the Monitoring Plan

The methodology allows for a range of monitoring approaches, including direct measurement (Quantification Approach 2) as well as the use of models (Quantification Approach 1) and default factors (Quantification Approach 3). Monitored parameters are collected and recorded at the sample unit scale, and emission reductions are estimated independently for every sample unit. The main objective of monitoring is to quantify stock change of soil organic carbon and emissions of CO_2, CH_4, and N_2O resulting from the project scenario during the project crediting period, prior to each verification.

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

- A description of each monitoring task to be undertaken, and the technical requirements therein;
- Definition of the accounting boundary, spatially delineating any differences in the accounting boundaries and/or quantification approaches;
- Parameters to be measured, including any parameters required for the selected model (additional to those specified in this methodology);
- Data to be collected and data collection techniques and sample designs for directly-sampled parameters;
- Modeling plan, if applicable;
- Anticipated frequency of monitoring, including anticipated definition of "year~~";~~".
- Baseline control site management plans (following annual schedule of activities), if applicable;
- 10-year baseline re-evaluation plan, detailing source of regional (sub-national) agricultural production data and procedures to revise the baseline schedule of ~~management~~ activities ~~where necessary~~;
- Quality assurance and quality control (QA/QC) procedures to ensure accurate data collection and screen for, and where necessary, correct anomalous values, ensure

completeness, perform independent checks on analysis results, and other safeguards as appropriate;

- Data archiving procedures, including procedures for any anticipated updates to electronic file formats. All data collected as a part of monitoring process, including QA/QC data, must be archived electronically and be kept at least for two years after the end of the last project crediting period; and
- Roles, responsibilities and capacity of monitoring team and management.

9.3.1 Sample design

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

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

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

In general, variability in soil properties, including SOC stocks, increases as the project area grows. Numerous factors determine SOC heterogeneity at the landscape scale, including climate, topography, historical land use and vegetation, parent material, soil texture, and soil type. Stratifying the project area into homogenous strata defined by factors that influence SOC stocks will usually reduce errors associated with project-scale estimates of SOC stocks. The Soil Maps and Databases of the FAO SOILS PORTAL[41], e.g., the Harmonized World Soil Database, or locally available (digital) soil maps can help choose different strata. In addition, soil texture can be easily estimated in the field~~(Vos *et al.*, 2016)~~. Since land use and management history frequently align with existing fields, it is recommended to take field boundaries into account when delineating strata. Within each stratum, random sampling may be applied to ensure representativeness and avoid biases. Defined strata should remain stable over time.

It is recommended that the number of homogeneous sites (i.e., the number of strata) and soil composite samples are increased to the maximum that can be afforded. The number of years

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

required to detect SOC stock changes decreases with increasing sample number. Compositing or bulking soil samples can help better represent spatial variability but might reduce the ability to detect SOC stock changes over time. It is therefore recommended to take at least 3-5 composite samples within each stratum for model validation (true-up) or when using quantification approach 2 measure and re-measure. For re-sampling purposes, georeferencing of sampling locations[42] and consideration of seasonal variability[43] is essential.

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

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

Equation 88

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

Where:

MDD	minimum detectable difference
S	standard deviation of the difference in SOC stocks between t_0 and t_1
n	number of replicates
$\nu = n - 1$	degrees of freedom for the relevant t-distribution
t	values of the t-distribution given a certain power level ($1-\beta$) and α level (i.e., significance level)

Equation 89

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

Where:

n	number of samples,
MDD	minimum detectable difference,
S	estimated standard deviation,
t_α	two-sided critical value of the *t*-distribution at a given significance level (α) frequently taken as 0.05 (5%), and

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

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

t_{β} one-sided quartile of the t-distribution corresponding to a probability of type II error β (e.g., 90%).

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

9.3.2 Modeling plan

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

Baseline control site management plan Quantification Approach 2 is applied, and no applicable performance benchmark is available, a baseline control site will be linked to one or more sample units. The location and boundaries, and demonstration of similarity criteria (see Table 7 ~~Table X~~) for each baseline control site will be documented. A management plan will be developed for each baseline control site, with adequate detail to permit implementation of the annual schedule of activities as determined for the linked sample unit(s).

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APPENDIX 1: NON-EXCLUSIVE LIST OF POTENTIAL IMPROVED ALM PRACTICES THAT COULD CONSTITUTE THE PROJECT ACTIVITY

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

Reduced fertilizer (organic or inorganic) application

- Optimized fertilizer application
- Organic fertilizer application (e.g., manure, compost)
- Rice - Urease inhibitor (e.g., NBPT, or controlled release fertilizer)

Improve water management/irrigation

- No irrigation
- Rice - alternative wetting and drying (AWD)

Reduce tillage/improve residue management

- Reduced tillage/Conservation tillage
- Strip-till/Mulch-till
- ~~Continuous n~~No-till
- Crop residue retention

Improve crop planting and harvesting

- Rotational commercial crop
- Continuous commercial crop with cover crop
- Rotational commercial crop with cover crop
- Double cropping
- Relay cropping

- Intercropping of cover crop with commercial crop (e.g., improved agroforestry) during the same growing season
- Incorporate fungal/microbial inoculant or other soil probiotic

Improve grazing ~~practices~~management

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

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[44] caused by direct or indirect human-induced processes. This equates to hundreds of millions of hectares of degraded crop- and grasslands with reduced productive capacity, which adversely affects livelihoods and ecosystems and the ability to meet humanity's growing needs.

Degraded lands can be restored and rehabilitated through implementation of sustainable land management strategies, thereby reversing degradation and restoring productivity. In addition, such strategies can reduce conversion pressure on native ecosystems, generate new income opportunities, and provide ecosystem services such as erosion control, regulation of groundwater recharge, and enhanced above- and belowground biodiversity and carbon stocks.

Given the multiple benefits of restoration, this methodology seeks to incentivize restoration of degraded crop- and grasslands by making an exception to the land use change applicability condition that otherwise requires project lands to remain cropland or grassland throughout the project crediting period. This exception, however, requires a two-step process to credibly demonstrate 1) current and future degradation of lands in the baseline scenario, and 2) expected improvements in soil health and associated socioenvironmental outcomes through the introduction of improved practices involving land use change.

1. **Demonstration of land degradation.** The project proponent shall use the CDM *Tool for the identification of degraded or degrading lands for consideration in implementing CDM A/R project activities*[45] to demonstrate both that the land is degraded at the start of the project and that the land will continue to degrade in the baseline scenario. The Tool uses a two-stage process that involves:

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

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

a. identification of project lands classified as degraded under any verifiable local, regional, national or international land classification system or credible study produced within the last ten years; or

b. in the absence of such study, through direct evidence based on indicators of degradation or through comparative studies. Exact procedures are outlined in the Tool.

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

APPENDIX 3: RECOMMENDED PROCESS FOR ASSESSING WHETHER NEW PROJECT ACTIVITY INSTANCES ARE COMMON PRACTICE

Section 3.5.15 of the VCS Standard, v4.0[46] sets out the eligibility criteria requirements that grouped projects must develop and include in their project description. These eligibility criteria are a set of project-specific criteria that serve as a screen to determine if any new project activity instances meet the baseline scenario and have characteristics with respect to additionality that are consistent with the initial project activity instances. The addition of new instances does not impact the additionality of the instances already included in the project.

Figure 5 outlines a recommended approach for assessing common practice of new project activity instances and identifies when a new weighted average should be calculated (See Section 7 for further details). New instances ~~of any activity or combined activity (i.e., two or more activities on the same field)~~ whose adoption rate on their own (i.e., as single or combined (two or more) activities) were below 20% in the applicable ~~state/province (or equivalent 2nd order jurisdiction)~~ stratum at validation are automatically deemed additional. New instances of any individual activity or combined activity that were not included in the initial assessment of additionality, but with a current existing adoption rate below 20% are also deemed additional.

If the project proponent seeks to add new activities or combined activities that are non-additional on their own (i.e., with single or combined adoption rates currently greater than 20%) in a given ~~state/province~~stratum, a new weighted average should be calculated (See Step 2 of Section 7). To calculate the weighted average project proponents should use the total area across the entire project currently under each management activity (i.e., old and new activity instances). Further, on fields where new project activities have been added to existing project activities since the last monitoring period, the combined activity adoption rate should be used. For example, if an area of land entered the project at the outset by adopting cover cropping, and in subsequent years also adopted reduced tillage, the adoption rate for the combined activities (i.e., both activities on a given land area) should be used for that land.

To determine adoption rates for the purpose of re-calculating the weighted average or assessing whether a new practice not previously assessed in a given ~~state/province~~stratum is common practice, the project proponent should use the most current and high quality data available (See Step 2 of Section 7 for further guidance on appropriate data sources). However, the project proponent may exclude their own activity instances from the adoption rate, so long as those instances have already

[46] https://verra.org/wp-content/uploads/2019/09/VCS_Standard_v4.0.pdf

been deemed additional and have been successfully verified at least once. In this way, the project proponent is not penalized for successful implementation of a given activity in a given region.

If a given activity is deemed common practice in a ~~state/province~~stratum through a re-calculated weighted average~~ (and therefore considered non-additional if applied on its own)~~, growers that were previously implementing, and being credited for, the activity on a portion of their land should still be eligible to be credited for the expansion of the activity throughout their farm. However, any expansion in activity area should be included in current and future weighted average calculations in relation to eligibility of new growers, which will affect what other activities, may be added without exceeding the 20% threshold.

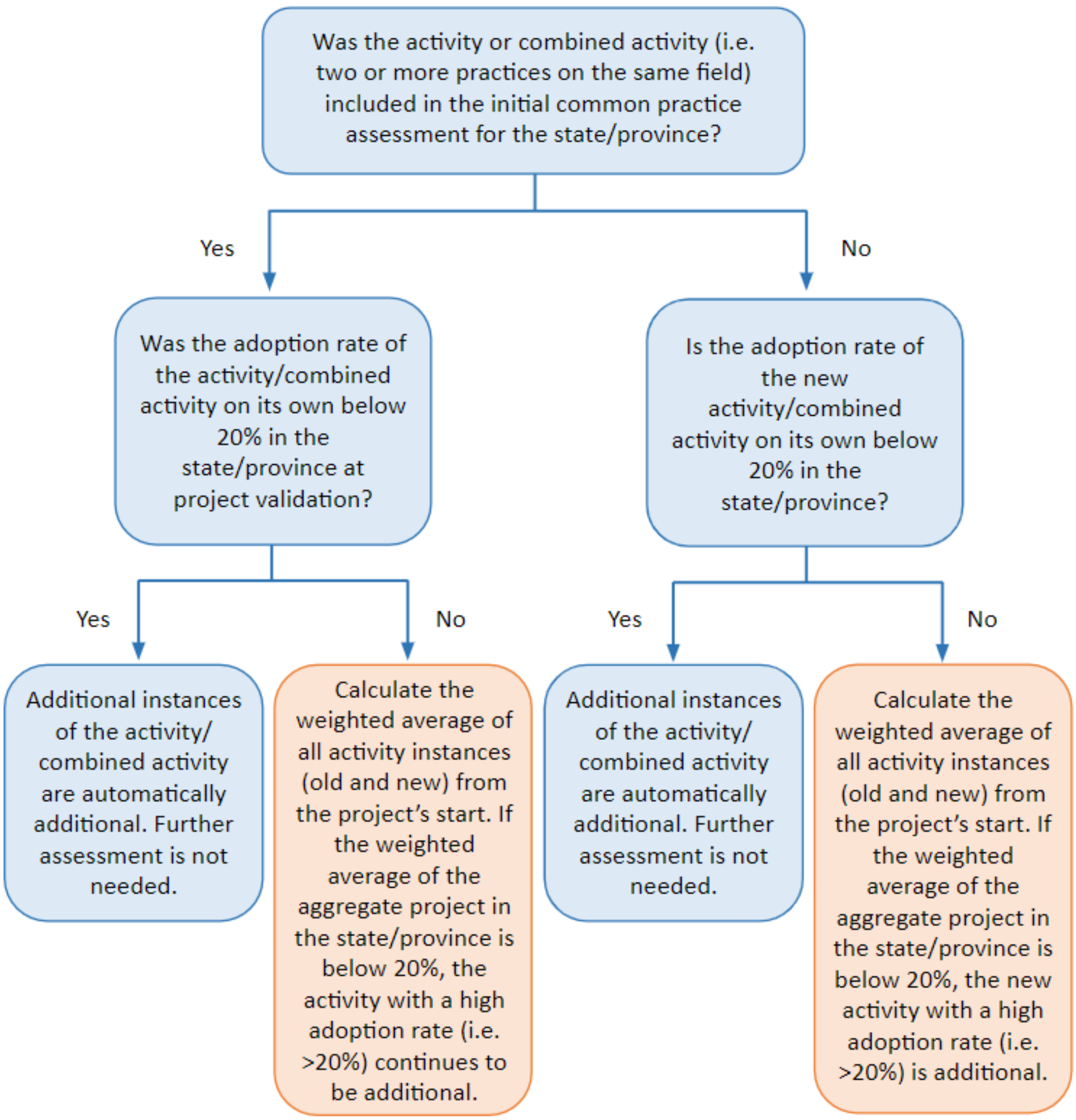

Figure 5: Flowchart for establishing when the weighted average should be re-calculated with the new activity instances for common practice demonstration

APPENDIX 4: GUIDANCE ON POTENTIAL EMERGING TECHNOLOGIES TO MEASURE SOC STOCKS

As indicated in Table 6 and Table 8~~Tables 6 and 7~~ and parameter table (section 9.2) related to modeled and measured SOC, projects may use emerging technologies to determine SOC content if sufficient scientific progress has been achieved in calibrating and validating measurements, and uncertainty is well-described. This appendix provides guidance on requirements for using such emerging technologies and a non-exhaustive list of potential technologies (with a focus on proximal sensing) to determine SOC content and criteria to ensure their robustness and reliability[47].

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

Table 9~~Table 1~~ presents potential emerging proximal sensing technologies which research and publications have shown to hold promise for streamlining SOC measurement. Although proximal sensing techniques may not be as precise per individual measurement compared to conventional analytical laboratory methods, e.g., dry combustion, proximal sensing may be more cost-efficient and provide a better balance between accuracy and cost. Hence, although each individual measurement may be less accurate, many more measurements can be made across time and space than would be feasible with conventional methods, enabling an overall estimate of carbon stock that is of similar or better accuracy than lower density sampling that is measured with conventional analytical laboratory methods. Since many more proximal devices may be used in a project than would be used if all samples were sent to a single lab, care must be taken to demonstrate device to device calibration and precision. Project developers must provide details to the VVB on the criteria and considerations of the emerging SOC measurement technology as specified in ~~Table 1~~ Table 9. Projects should maintain adherence to these criteria over time to ensure that measurement and re-measurement are conducted under the same conditions and are thus comparable. While the focus is on proximal sensing, Verra is tracking developments related to remote (e.g., satellite) sensing of SOC stocks and future revisions to

[47] The listed technologies may be updated in future versions of VM0042

this appendix may include guidance on using remote sensing for direct SOC measurement if that technology is demonstrated as scientifically credible.

Table 9: Criteria to evaluate the use of emerging technologies based on proximal sensing to measure SOC content

Method	Criteria and considerations to ensure robustness and reliability
Inelastic neutron scattering[48] (INS)	• If carbonates are present (calcareous or limed soils), inorganic C must be separately accounted for. • Inorganic gamma scintillators (detectors based on the sodium iodide NaI(Tl), bismuth germinate BGO, and lanthanum bromide $LaBr_3(Ce)$) are better suited due to their higher efficiency of registering gamma rays in the energy range up to 12 MeV. • Pulsed Fast/Thermal Neutron Analysis (PFTNA) is the most suitable for soil neutron-gamma analysis. It allows separating the gamma ray spectrum due to INS reactions from the thermal neutron capture and the delay activation reaction spectra. • Locally adapted calibration procedures must be included in the project documentation for VVB review.
Laser-induced breakdown spectroscopy (LIBS)	• Soil samples must be dried for at least 24h at 40°C. • If carbonates are present (calcareous or limed soils), samples must be acid-washed. • Soil samples must be milled for homogenization and particle size reduction to facilitate the evaporation and atomization process in the plasma. • Before analysis, soil material must be pressed to form a pellet with a flat surface. • When measuring directly in the field (in-situ), appropriate corrections to remove soil moisture and further matrix effects must be applied. • The configuration of the LIBS instrumental parameters should be optimized for each matrix. The laser pulse energy and the diameter of the laser beam (i.e., spot size) should be monitored simultaneously in the laser pulse fluence term (laser pulse energy per unit area, J cm^{-2}) as well as delay time, laser repetition rate, etc. • Projects may rely on chemometric methods for signal analysis, spectral preprocessing, and subsequent data processing and interpretation, including reducing matrix effects. • A description of the locally adapted calibration procedures must be included in the project documentation for VVB review. Multiple linear regression has proven to be an effective calibration strategy to tackle interference in soil carbon analysis. Further "non-traditional calibration strategies"[49] may

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

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

	be applied, which explore the plasma physicochemical properties, the use of analyte emission lines/transition energies with different sensitivities, the accumulated signal intensities, and multiple standards to obtain a linear model or calibration curve. • Multiple laser shots per sample may improve the measurement results.
Mid-infrared (MIR) and visible near-infrared (Vis-NIR and NIR) spectroscopy, including diffuse reflectance spectroscopy (DRS) and diffuse reflectance infrared Fourier transform (DRIFT) measurements	• For MIR and NIR, soil samples must be air or oven-dried, crushed or sieved to a size fraction smaller than 2 mm, avoiding preferential sieving. • When measuring directly in the field (in-situ), appropriate corrections to remove soil moisture and further matrix effects must be applied. • The applied spectrometer should have a spectral resolution of 10 nm or less across the visible and near-infrared range (between 400 and 2500 nm), and spectra should be recorded in this range at 1 nm intervals. • Measurement protocols should be used when available, such as Appendix B in (Viscarra Rossel *et al.*, 2016) for Vis-NIR or the Standard Operating Procedures of the Soil-Plant Spectral Diagnostics Laboratory of World Agroforestry Centre (ICRAF) • Calibration through multivariate statistics or machine-learning algorithms has been performed using large spectral libraries[50] or new site-specific libraries developed with local soil samples (higher accuracy). Sub-setting or stratifying the dataset can provide better calibration results. See (England and Viscarra Rossel, 2018) and (Stevens *et al.*, 2013) for further guidance on calibration techniques and spectroscopic model development and validation. • Calibration procedures must be included in the project documentation for VVB review.

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

INS

Izaurralde, R. C. et al. (2013) 'Evaluation of Three Field-Based Methods for Quantifying Soil Carbon', PLOS ONE, 8(1), p. e55560. doi: 10.1371/journal.pone.0055560.

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

Kavetskiy, A. et al. (2017) 'Neutron-Stimulated Gamma Ray Analysis of Soil', in New Insights on Gamma Rays. Intech Open. Available at: https://www.intechopen.com/books/new-insights-on-gamma-rays/neutron-stimulated-gamma-ray-analysis-of-soil.

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

LIBS

Costa, V. C. et al. (2020) 'Calibration Strategies Applied to Laser-Induced Breakdown Spectroscopy: A Critical Review of Advances and Challenges', 31(12). doi: https://doi.org/10.21577/0103-5053.20200175.

Fernandes Andrade, D., Pereira-Filho, E. R. and Amarasiriwardena, D. (2021) 'Current trends in laser-induced breakdown spectroscopy: a tutorial review', Applied Spectroscopy Reviews, 56(2), pp. 98–114. doi: 10.1080/05704928.2020.1739063.

Senesi, G. S. and Senesi, N. (2016) 'Laser-induced breakdown spectroscopy (LIBS) to measure quantitatively soil carbon with emphasis on soil organic carbon. A review', Analytica Chimica Acta, 938, pp. 7–17. doi: 10.1016/j.aca.2016.07.039.

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

Barthès, B. G. and Chotte, J.-L. (2021) 'Infrared spectroscopy approaches support soil organic carbon estimations to evaluate land degradation', Land Degradation & Development, 32(1), pp. 310–322. doi: 10.1002/ldr.3718.

Dangal, Shree R.S., Jonathan Sanderman, Skye Wills, and Leonardo Ramirez-Lopez. 2019. "Accurate and Precise Prediction of Soil Properties from a Large Mid-Infrared Spectral Library" Soil Systems 3, no. 1: 11. https://doi.org/10.3390/soilsystems3010011

England, J. R. and Viscarra Rossel, R. A. (2018) 'Proximal sensing for soil carbon accounting', SOIL, 4(2), pp. 101–122. doi: 10.5194/soil-4-101-2018.

Ng, W., Minasny, B., Jones, E. and McBratney, A. (2022) 'To spike or to localize? Strategies to improve the prediction of local soil properties using regional spectral library', Geoderma, 406, https://doi.org/10.1016/j.geoderma.2021.115501

Nocita, M. et al. (2015) 'Chapter Four - Soil Spectroscopy: An Alternative to Wet Chemistry for Soil Monitoring', in Sparks, D. L. (ed.) Advances in Agronomy. Academic Press, pp. 139–159. doi: 10.1016/bs.agron.2015.02.002.

Reeves, J. B. (2010) 'Near- versus mid-infrared diffuse reflectance spectroscopy for soil analysis emphasizing carbon and laboratory versus on-site analysis: Where are we and what needs to be done?', Geoderma, 158(1), pp. 3–14. doi: 10.1016/j.geoderma.2009.04.005.

Sanderman J, Savage K,Dangal SRS. Mid-infrared spectroscopy for predictionof soil health indicators in the United States. Soil Sci.Soc. Am. J. 2020;84:251–261.https://doi.org/10.1002/saj2.20009

Seybold, C.A., et al., 'Application of Mid-Infrared Spectroscopy in Soil Survey', Soil Sci.Soc. Am. J. 2019; 83: 1746-1759. https://doi.org/10.2136/sssaj2019.06.0205

Stevens, A. et al. (2013) 'Prediction of Soil Organic Carbon at the European Scale by Visible and Near InfraRed Reflectance Spectroscopy', PLOS ONE, 8(6), p. e66409. doi: 10.1371/journal.pone.0066409.

Viscarra Rossel, R. A. et al. (2016) 'A global spectral library to characterize the world's soil', Earth-Science Reviews, 155, pp. 198–230. doi: 10.1016/j.earscirev.2016.01.012.

Viscarra Rossel, R. A. and Webster, R. (2012) 'Predicting soil properties from the Australian soil visible–near infrared spectroscopic database', European Journal of Soil Science, 63(6), pp. 848–860. doi: 10.1111/j.1365-2389.2012.01495.x.

APPENDIX 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 (percent)**	**Upper (percent)**
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) Soil Survey Manual, Handbook No. 18 Chapter 2.—Landscapes, Geomorphology, and Site Description Table 2-3 https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054252