METHODOLOGY 01

Adoption of Regenerative Land Management

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1. Definitions

Baseline scenario
Reference case that best represents the conditions most likely to occur in the absence of a proposed GHG project.

Co-Benefit
A Co-Benefit is defined as a positive side effect on an ecosystem that is attributable to the application of sustainable land management practices.

Farmer
The person acting as the land steward and responsible for the implementation of the project activities.

Monitoring report
A report prepared by the project proponent and the farmer for each monitoring period. The report is archived and serves as a performance tracking tool.

Project activities
Predefined land management practices carried out throughout the project period.

Project area
The project area includes any land on which the project work is carried out.

Project description
A document, created by the project proponent, demonstrating conformity of the project with the requirements of the present methodology and consistency with verification and validation needs.

Project documentation
Recording of the key project details and documents that are required to implement it successfully. It includes all documents created over the course of the project.

Project period
Predefined period of time in which project activities are carried out.

Project proponent
Individual or organization that has overall control and responsibility for a GHG project.

Project scenario
Reference case that best represents the conditions most likely to occur in the presence of a proposed GHG project.

Credit Class Document Requirements of registry necessary to issue credits. The content of this document includes among other content, a definition of timing schedules, allocation of credits to buffer pools and specific data collection protocols.

2. Conditions and Boundaries

This methodology serves as an approach to measure carbon sequestration, reduction of greenhouse gas emissions and improvement of ecosystem health through regenerative land management in the agricultural landscape. Practices defined as regenerative are inter alia the use of cover crops, returning crop residues, reduced/no tillage or introducing agroforestry into the landscape. The methodology is applicable where carbon or carbon equivalents within a defined project boundary would remain unchanged or decrease over time in the absence of the project activity. Where applicable, considered greenhouse gasses emitted within the project boundary are: methane, nitrogen and carbon dioxide. The co-benefits considered to assess ecosystem health depend on the project site and individual project conditions.

The methodology is designed to calculate the carbon sequestration potential through modelling based on the RothC model.

This methodology integrates the latest versions of the following methodologies and tools:

1. CDM A/R Tool "*Estimation of carbon stocks and change in carbon stocks of trees and shrubs" in* A/R CDM "*project activities and Simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under the clean development mechanism implemented on grasslands or croplands"* AR-AMS0001e
2. CDM A/R Tool "*Project activities and simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under the clean development mechanism implemented on grasslands or croplands"*
3. CDM A/R Methodological tool *"Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities"*
4. VSC Methodology VM0042 (2020): Methodology for improved agricultural land management VM0042, v1,0.
5. Report of EB 33, Annex 16. A/R Methodological tool "Estimation of direct nitrous oxide emission from nitrogen fertilization".

2.1 Conditions for Applicability of the Methodology

This methodology is applicable to projects, practicing regenerative land management, only under the conditions listed below. Practices considered as regenerative are inter alia the use of cover crops, returning crop residues or introducing agroforestry into the landscape.

1. The project is not implemented on water logged soils.
2. The respective land is either cropland or grassland at the project start. Other land types may be considered with appropriate methodological adjustments and validation.
3. Studies must prove that the implemented model can be applied in the targeted region and local climate. Model validation for a project region is performed as described in the respective chapter (4.4.2.4).

The land title and thus the ownership must be clear before the project start. 2.2 Project Boundaries

This module defines the criteria on which the selection of carbon stocks and greenhouse gas emission sources within the project boundaries is based. Furthermore, it outlines the standards by which the temporal and spatial boundaries of the project are to be selected and documented.

2.2.1 Spatial boundaries

The project area is documented by georeferenced data which can be stored in the form of polygon shapefiles, GPS coordinates or KML files. It includes any land on which the project work is carried out.

2.2.2 Temporal boundaries

The project time frame is defined before monitoring work begins. The project description includes the start and end date of the project activity, the start and end date of the crediting period and reporting milestones, including set reporting periods.

The reporting period and the frequency with which the time limits are established adhere to the following guidelines:

1. A common project length is 10 years.
2. A project description is elaborated at the start of the project period.
3. Monitoring of the required data points shall be carried out each year during the life of the project.
4. The farmer provides data on activities, changes in practices and crop yield as well as data for the Carbon dioxide equivalent (CO2eq) Emission Balance at the end of each monitoring period.
5. Regular reports are prepared on the basis of the monitored data. The number of planned reports shall be documented in the project description.
6. With each reporting round, the number of carbon credits is recalculated based on the monitoring data. A document is created which describes the progress of the project in a traceable scoring procedure and contains the number of credits reassessed.
7. The reporting time frame outlined in the project description can be modified for various reasons, such as occurrence of extreme weather events. A change in the schedule shall be justified and documented.
8. The reporting periods shall not be shorter than one year.

2.2.3 Carbon stocks and greenhouse gas emission sources

Table 1: Carbon stocks to be included or excluded from the project boundary

Carbon stocks	Included	Description

Above ground biomass of woody perennials	included	The above ground biomass is calculated using the CDM A/R Tool "*Estimation of carbon stocks and change in carbon stocks of trees and shrubs"* in A/R CDM "*project activities and Simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under the clean development mechanism implemented on grasslands or croplands"* AR-AMS0001e. Annual crops are not included in this framework.
Below ground biomass of woody perennials	optional	The below ground biomass is calculated using the CDM A/R Tool *"Estimation of carbon stocks and change in carbon stocks of trees and shrubs* in A/R CDM *"project activities and Simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under the clean development mechanism implemented on grasslands or croplands*" AR-AMS0001e.
Soil organic carbon	included	Major carbon stocks to be assessed in this framework

Source: This table is modified on the basis of Table 2 taken from the VCS Methodology VM0042 (2020)

Table 2: Greenhouse gas emission sources to be included in the project boundary

Source	GHG	Description/explanation
Emissions due to use of fossil fuels	CO_2	Respective emission sources include all equipment that require fossil fuels for operation. This includes vehicles such as trucks, tractors, etc..
Emissions due to N-fixing species	N_2O	If N-fixing species are present in the project boundaries nitrous oxide emissions are considered
Enteric fermentation	CH_4	Emission source is relevant if livestock is present in the baseline or project scenario
Manure deposition	CH_4	Emission source is relevant if livestock is present in the baseline or project scenario
Manure and Urea deposition	N_2O	Emission source is relevant if livestock is present in the baseline or project scenario
Use of nitrogen fertilizer	N_2O	Emission source is quantified if nitrogen fertilizer is applied in the baseline or project

		scenario
Woody biomass	CO_2	Quantified as stock change in the stock (no emission source)
Soil organic carbon	CO_2	Quantified as stock change in the stocks (no emission source)

Source: This table is modified on the basis of Table 3 taken from the VCS Methodology VM0042 (2020)

2.3 Demonstration of additionality

All projects that pursue the objective of certification on the basis of the present methodology are required to demonstrate additionality. In order for the project to be considered additional, it must be demonstrated that:

1. Barriers exist preventing the implementation of the project activities (Barrier analysis); and;
2. It can be demonstrated that the project activities are not common practice in the project area (Common practice analysis).

2.3.1 Barrier Analysis

The project proponent must analyze whether barriers exist that prevent the implementation of the project activities. Thus, demonstrating that the project would not have been implemented without the resulting benefits of carbon certification. Barriers must be listed and described.

Barriers for project implementation could include:

1. Investment barriers
2. Knowledge barriers
3. Institutional barriers
4. Technological barriers
5. Barriers due to regional traditions
6. Barriers evolving through existing land management practices
7. Barriers through ecological circumstances

A more detailed list of potential barriers can be found in the A/R Methodological tool *"Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities"*

2.3.2 Common Practice Analysis

The project proponent must analyse if suggested project activities are common practice in the region where the site is located. The common practice analysis is suggested to be performed as demonstrated in Step 4 of the CDM A/R Methodological tool *"Combined tool to identify the* *baseline scenario and demonstrate additionality in A/R CDM project activities".* Deviations from the suggested method shall be documented adequately.

The outcome of the common practice analysis is the decision whether a project activity is considered additional or not. If a proposed project activity is declared to be "common practice" then the practice is not additional. If the proposed activity is declared not to be "common practice" then the practice is additional.

2.4 Principles

The implementation of the present Methodology follows the principles outlined in ISO 14064-2:2019. The application of principles is fundamental to ensure that GHG-related information is true. The principles apply to the entire methodology and are serving as a guiding tool during implementation.

Relevance

Select the GHG sources, sinks and reservoirs (SSRs), data and methodologies appropriate to the needs of the intended user.

Completeness

Include all relevant GHG emissions and removals. Include all relevant information to support criteria and procedures.

Consistency

Enable meaningful comparisons in GHG-related information.

Accuracy

Reduce bias and uncertainties as far as is practical.

Transparency

Disclose sufficient and appropriate GHG-related information to allow intended users to make decisions with reasonable confidence.

Conservativeness

Use conservative assumptions, values, and procedures to ensure that GHG emission reductions or removal enhancements are not over-estimated.

2.5 Permanence

Farmers shall be assessed on a range of criteria to understand the risk that there is reversal of the GHG emissions reductions, reducing the permanence of this project. These criteria shall be checked at the onset of the project, and annually as part of the MRV. To ensure the permanence of a project, a share of credits shall be allocated to buffer pool(s).

The use of buffer pool(s) is intended to cover unforeseen events that impact the removal of carbon in the project area over the longer term. These include but are not limited to:

- Implementation of activities that reverse carbon removals
- Major climate disaster

The percentage of credits allocated to buffer pools shall be decided by the project proponent based on the assessed risk of the project. This methodology recommends a share of credits between 5% and 20% to be allocated. The conditions regarding the distribution of these credits at the end of the project period shall be defined in the Credit Class Document.

2.6 Project Description and Reporting

A project description has to be created for every project, that is developed according to the present methodology. The document is prepared by the project proponent. It serves as a tool to demonstrate conformity of the project to the requirements of the methodology and consistency with verification and validation needs. The below listed information must be included in the project description:

- Project title, purpose and objective
- Roles and responsibilities, including contact information of the project participants
- Spatial boundaries of the project, including details on the geographical location, allowing for unique identification and delineation of the project area
- Temporal boundaries (as mentioned in chapter 2.3.2), listing
    - the date of initiation of the project activities
    - termination date of the project
    - frequency of monitoring and reporting
- Scope of the project, describing the relevant GHG pools
- Land use type of the identified parcels within the project area
- Pedo-climatic zone in which the project area is located
- Summary of the project activity
- Definition of the baseline scenario, listing the relevant baseline parameters
- Definition of the project scenario
- Expected carbon to be sequestered over the project period
- List of tracked Co-Benefits
- Risk assessment and proposal for management of identified risks
- Summary of the soil sampling process and outcome of the soil analysis (if applicable, see more on soil data strategy in chapter 4.3). Any deviation from the present methodology, including a precise documentation and justification

The project description document serves to establish specifications of the project. It is the basis for an external verification and validation. More details on the monitoring and reporting can be found in chapter 6.

2.7 Data Quality Management

A description of how data quality management is pursued is required to be provided in the project description of a crediting project. The description must contain details on quality assurance and quality control (QA/QC) procedures to ensure:

- accurate data collection
- completeness
- independent checks on analysis results
- trackable data archiving methods, including any anticipated updates to electronic files
- that data is archived electronically and kept for 5 years after the end of the last project crediting period
- data protection
- a transparent uncertainty assessment.
- a statement on how version control (of applied models, methodologies, tools, etc.) is handled

2.8 Aggregated Project

A set of projects can be aggregated for purposes of validation, monitoring and verification. Respective projects must fulfill the following criteria to be aggregated:

- project areas must be located in the same pedo-climatic zone (see chapter 4.2)
- the project areas are classified based on the primary land use type (see chapter 4.2)

2.9 Validation and Verification

This section provides a general overview of the requirements for validation and verification of the GHG benefits assertions for each project. Validation and Verification shall be carried out by an independent expert or organisation with adequate technical and auditing experience.

2.9.1 Validation

Project validation
Third-party validation shall be carried out for all projects at the project start, or at the time of the first project verification. The third-party validator checks the conformity of the project characteristics with the project description and the correct application of the present methodology. Validation is carried out based on a desk-based review of relevant project data and documentation. The findings shall be documented in a validation report.

Carbon model validation
For each pedo-climatic zone, the carbon model is validated and a corresponding report is developed and published at the start of the first project. This model validation is performed by the project proponent, in accordance with the procedure specified in section 4.4.2.4. For projects implemented within the same climatic zone, no new model validation is required.

2.9.2 Verification

Third-party verification of a project is carried out after project implementation has commenced and before the first CO2eq reduction or removal credits are issued. The following aspects shall be assessed during verification:

- The extent to which project activities have been implemented in accordance with the project description;
- The extent to which monitoring procedures have been implemented in conformance with the monitoring plan;
- The reliability of the evidence for the determination of CO2eq reductions and removals, as presented in the monitoring report;
- The correct application of formulae and methods set out in the project description for calculating baseline emission and project emissions;
- The accuracy of the calculated CO2eq emission reductions and removals in accordance with the project description and applied methodology.

An additional project verification is conducted at least one more time throughout the project period.

2.10 Public consultation and ongoing communication

To allow public consultation and ongoing communication, documentation and models will be made publicly available. Project descriptions shall be published on the Registry. All applied models are accessible on Github via the climatefarmers page.

3. Project Stages Overview

The project consists of three components: baseline emissions and removals, estimated project emissions and removals and the monitoring of emissions and removals throughout the duration of the project. The methodology for each of these components is described below.

3.1 Methodology to define the baseline

The baseline emissions and removals are calculated using the following steps:

1. Define and document project boundaries.
2. Outline the baseline scenario.
3. Quantify the annual emissions (CO2eq) in the baseline scenario.
4. Account soil organic carbon stocks.
5. Model the baseline scenario over the time horizon of the project.
6. Assess the current status of co-benefits.

3.2 Methodology to define the project

The project emissions and removals are estimated using the following steps:

1. Outline the project activities scenario and demonstrate additionality based on the project boundaries defined in the baseline scenario.
2. Quantify initial CO2eq.
3. Model the project scenario over the time horizon of the project using the SOC measured in the baseline.
4. Calculate the difference between baseline and the project SOC over time.
5. Calculate uncertainty.
6. Assess potential leakage.
7. Assess the status of co-benefits.

3.3 Methodology for Monitoring

The monitoring process includes following steps:

1 Obtain data to complete annual CO2eq Emission Balance.
2 Assess the current status of co-benefits.
3 Obtain information about the practices that were implemented.

The data here can be obtained from a combination of sources, including but not limited to farmer questionnaires, satellite monitoring and onsite visits.

4. Methods relevant for all project stages

Following methods are relevant across chapters.

4.1 Stratification of the Project Area

The project area may be divided into parcels (stratification) if a variety of land management practices are in place. The parcels shall be distinguished by variations of the characteristics in Table 3. Additional characteristics may be relevant depending on the project. The parcels are analyzed individually for their carbon removal and emission reduction potential. Further stratification of the parcels may be performed in the process of soil sampling (See Chapter 4.3).

Table 3: Description of characteristics and practices for stratification of project area

Geographical characteristics or Management Practice	Qualitative	Quantitative
Crop types (planting and harvesting practices)	- Crop types	- approximate date(s) planted (if applicable) - approximate date(s) harvested / terminated (if applicable)
Application of fertilizer	- Manure	- Manure type and

	- Compost - Nitrogen fertilizer	application rate (if applicable) - Compost type application rate (if applicable) - N application rate (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)
Hydrology/water management	- Irrigation (Y/N) - Flooding (Y/N)	- irrigation rate (if applicable)
Grazing practice	- Grazing (Y/N) - Animal type (if applicable)	- annual length of grazing period (if applicable) - number of animals (if applicable)
Soil properties	- see chapter 4.3	- see chapter 4.3

Source: Modified table, based on the VCS Methodology "VM0032" (2015) and the "Soil Organic Carbon Framework Methodology" by gold standard (2020)

Once the project area is stratified, each parcel is assigned a land use type, as outlined below.

4.2 Pedoclimatic Zones and Land Use Types

Each identified parcel of a project area is assigned a specific Land Use Type (see Table 4). The project area itself is assigned to a pedo-climatic zone (see Figure 1). This classification process serves the model calibration approach and the soil data strategy followed by the present methodology. Both approaches, model calibration and soil data strategy, are described in following chapters.

The concept of pedo-climatic zones was first introduced by the European Union (Directorate-General for Environment (European Commission et al., 2013). The classification into 13 zones is based on an environmental stratification (i.e., the Environmental Zones (EnZs)) as seen in Figure 2, building on a combination of land, soil, and climate factors (I.e., pedo-climatic information).

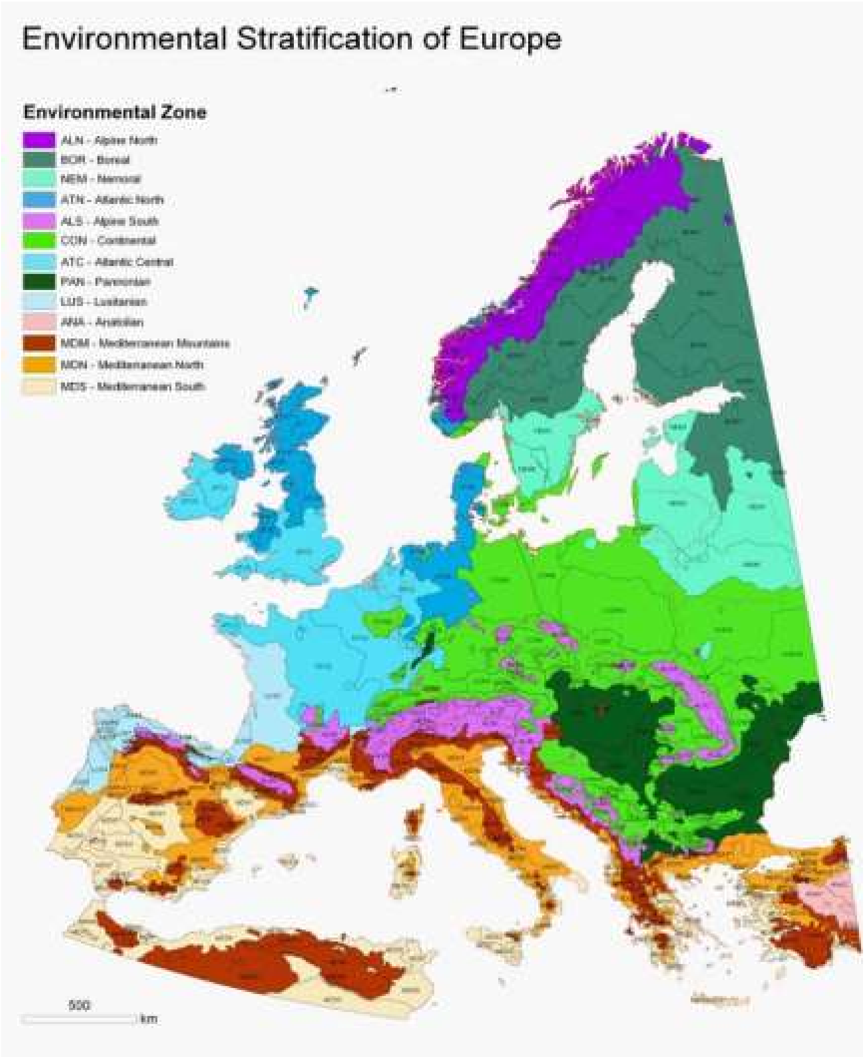

Figure 1: European pedo-climatic zones

Source: Directorate-General for Environment (European Commission) et al., 2013

The concept of Land Use Types builds on the stratification of the project area, as outlined in the previous chapter. A distinction between 5 major Land Use Types can be drawn. Each land use type is defined by a set of practices, as listed in the table below.

Table 4: List of land use types

Land Use Type	Description
Silvopasture	Agroforestry within grazed or harvested pastures
Arable Crops	Grazed or harvested
Grasslands	Grazed or harvested (hay)

Agroforestry	Fruit (or other) trees or bushes without grazing in between, harvestable pastures
Forestry	Timber production without grazing

The listed Land Use Types can be categorized into subtypes on the basis of climatic, vegetational, pedological and regionally specific land use adaptations (e.g., a Land Use Subtype of an Agroforest can be a Montado – a traditional Portuguese concept of agroforestry with distinct species of flora and fauna present in a holistic system). A project area can consist of several Land Use Types or Land Use Subtypes. The carbon sequestration potential is modelled individually for each identified Land Use (Sub-) Types within a project area.

4.3 Soil Data

Soil data is required for each Land Use Type (and Subtypes, if applicable) identified within a project area to calculate the carbon sequestration potential. Whether soil samples need to be taken or alternative sources can be considered is outlined below and visualized in Figure 2.

Soil samples are required to be taken in the following scenarios:

- Soil information necessary to run RothC are available for the pedo-climatic zone in question, but there is not data available for the Land Use Type(s) (or Land Use Subtype(s), if applicable).
- Soil information necessary to run RothC are available for the land use type but are from a different pedo-climatic zone than the one in which the project area is located.

Soil samples do not necessarily need to be taken for each parcel within a project area if several requirements are fulfilled. These criteria are listed below and must be met at all times if data is derived from other sources (e.g., open-source soil data platforms) rather than soil samples:

- The data must originate from within a radius of 200 km around the project area
- Open-source data or data retrieved from scientific literature are available for the pedo-climatic zone and the land use type in question, so that comparability with the geographical conditions (e.g., climate, elevation, geomorphology, soil type, etc.) can be demonstrated
- The land management practices of the assigned land use type must have been in place for at least the preceding three years
- The sampling methods and sample analysis methods of the data must be comparable
- If several data sets are available, the most recent is required to be used

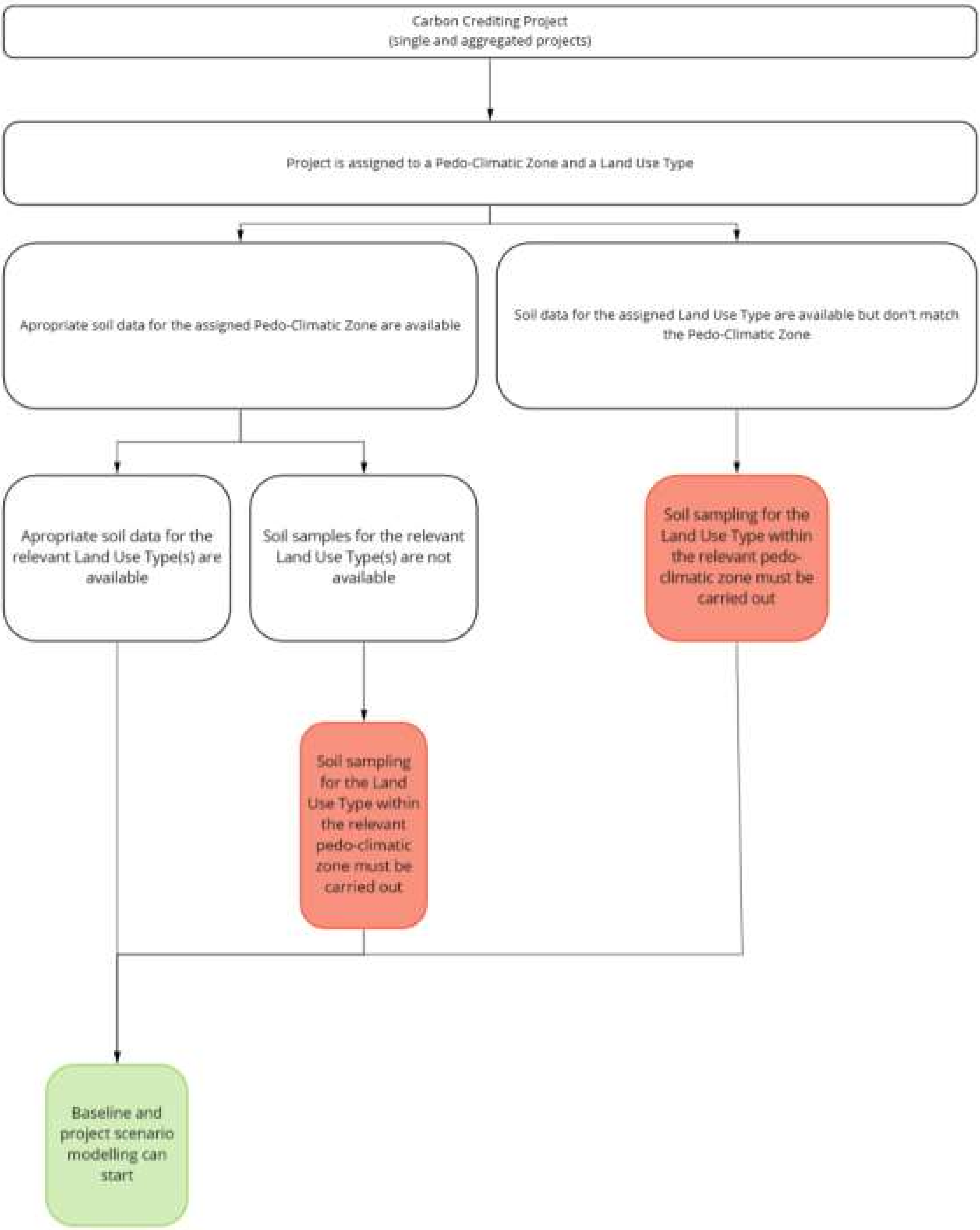

Figure 2: Soil Data Strategy

Regarding soil parameters, the RothC model requires data on soil organic carbon, clay content and bulk density. The data can inter alia be derived from the sources listed in the table below, following the aforementioned guidelines:

Table 5: List of potential data sources for soil parameters

Parameter	Derived from	Source
Soil Organic Carbon (SOC)	Soil sampling	On site soil sampling
	Open-source platform	WoSIS https://www.isric.org/explore/wosis
Clay content	Soil sampling	On site soil sampling
	Regional or national Soil maps	SoilGrids https://www.isric.org/explore/soilgrids
	Open-source platform	WoSIS https://www.isric.org/explore/wosis
Bulk density	Soil sampling	On site soil sampling
	Regional or national soil maps	SoilGrids https://www.isric.org/explore/soilgrids
	Open-source platform	WoSIS https://www.isric.org/explore/wosis

If soil sampling is performed, the process must be documented with following details:

- Map of the monitored landscape showing the identified parcels;
- Description of the method applied to stratify the landscape and to estimate the number of samples;
- GPS data of the locations where soil data was taken including the accuracy of the device;
- Sample depth (minimum 30 cm of sampling depth;
- Tools used to take the samples;
- Description of the overall sampling approach that was applied.

The methods listed below are accepted within this methodology to measure SOC concentration. If multiple soil samples are taken during the project, consistency of the measurement method is to ensure. Accepted methods are:

- Loss of ignition
- Dry combustion
- Walkley-Black method

If other methods are considered, these must be peer reviewed and provided with a source.

Although a variety of sampling strategies exist, the most commonly applied in soil science are simple random and stratified random sampling.

Simple random sampling is used to represent the entire monitored landscape where soil samples are randomly selected without any other consideration.

Stratified random sampling, on the other hand, can minimize the soil sample size by landscape stratification. In this procedure, the landscape is divided into strata characterized by similar pedological features within each of them. Therefore, a stratified sampling strategy will ensure that each subgroup is included in the analysis.

In order to successfully outline areas with similar features, a number of indicators can be considered. These include:

- Previous land management practices, affecting vegetation cover and above ground biomass.
- Catchment areas, watercourses and other hydrological features reflect soil properties additionally
- Slopes, erosion and general elevation determine the overall topographical conditions, affecting soil properties.
- If pedological characteristics such as pH value or clay content were measured previous to the project start, the results can be considered additionally.

If the variability of the features within the strata is low, the number of soil samples taken is proportional to the size of each stratum. In case of a high degree of variability within the stratum, the number of samples in a specific stratum rises according to its feature variability.

If the following aspects are considered thoroughly, the stratified sampling is likely to achieve better results than the simple random sampling:

- The landscape must be stratified before taking the soil samples.
- The identified strata must be exhaustive and mutually exclusive.
- The strata must differ in the soil properties, otherwise there is no gain achieved over simple random sampling.
- The selection of soil samples out of each stratum must be random.

4.4 Carbon modelling

Carbon modelling is an approach to predict the evolution of carbon stocks over a period of time in a predefined study area given a set of farm management practices. A number of models have been developed in recent decades to facilitate these predictions (Falloon and Smith, 2009; Manzoni and Porporato, 2009; Campbell and Paustian, 2015).

4.4.1 Eligibility criteria for the use of a carbon model

See section 2.1

4.4.2 RothC

The methodology in its current form is tailored for the application of the Rothamsted Carbon Model (RothC) (Coleman and Jenkinson, 1996).

4.4.2.1 Mathematical background

RothC is a model for the turnover of organic carbon in topsoil following effects of soil texture, temperature, moisture content and plant cover on the carbon turnover process, with a monthly time step (Coleman and Jenkinson, 1996).

RothC models soil carbon cycling through five distinct pools of decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO), humified organic material (HUM), and inert organic matter (IOM); each of which has its own decomposition rate. At each iteration, SOC or decomposition of new plant residues (carbon inputs adjusted by DPM/RPM ratio) feed microbiota (BIO) and add to the more slowly decomposing organic matter (HUM), as per Figure 1. The degradation of each carbon pool is equated as the initial SOC stock for that compartment adjusted by clay content, rate modifying factors for temperature, moisture, and soil cover, and a pool-specific degradation rate.

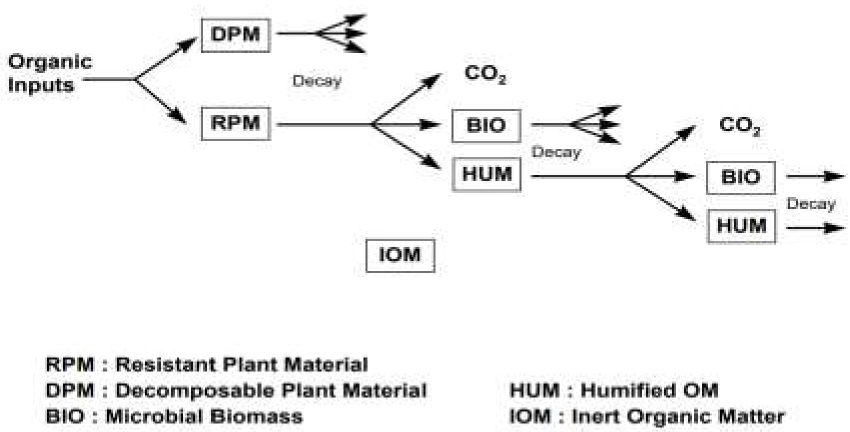

Figure 3: Flow of Organic inputs between the five pools that determine the turnover of organic matter according to the Roth C model. Source: Coleman & Jenkinson, 2014

The RothC model relies on the following input data:

- Climate: monthly data on air temperature, rainfall, and evapotranspiration
- Soil: soil depth (reporting and modelling of SOC changes is recommended to be performed for a 30 cm soil layer, as suggested in the IPCC (2006) guidelines), soil cover (bare or covered), clay content (%), initial SOC stock (SOC stock in the implementation of this model is derived from soil organic carbon concentration and bulk density)
- Carbon inputs: total amount of plant residues and/or farmyard manure. The model does not distinguish between above ground residues such as litter and below ground biomass such as root exudation

4.4.2.2 Implementation

An exemplary implementation of the RothC model, based on the RothC Model function from the SoilR package for R (Sierra and Mueller, 2012) can be found on GitHub. The documentation contains the most recent assumptions and additional features and is available open source. The repository can be found at [climatefarmers/soil-modelling: Modelling of Carbon in Soil (github.com)](). The version of the code that is implemented for a project shall be tagged and referenced in the project documentation.

Regardless of which model version is used to estimate carbon removals for a crediting project, an approach to model calibration and validation shall be outlined and applied. Both steps are considered as part of the verification of model performance and thus the quantification of credits. In the following two chapters, a possible method for calibrating and validating the RothC model for a project area is presented.

4.4.2.3 Model Calibration

Model calibration requires the input parameters and constants within RothC to be adjusted to increase model accuracy. The following procedure shall be carried out for each combination of baseline land use type and the pedo-climatic zone on which the model is applied. More details on land use types are to find in paragraph 4.2 of this document.

1. The most likely natural vegetation in the project area is identified through literature research.
2. Information on the climatic and soil related parameters is extracted from peer-reviewed scientific publications and databases such as the Copernicus Data Store and WoSIS (Copernicus Climate Change and Atmosphere Monitoring Services; Batjes et al. 2019).
3. The Roth C model is run in inverse mode to solve for the carbon input necessary to obtain an equilibrium with the observed carbon content (Coleman and Jenkinson, 1996; Francaviglia et al., 2012).
4. The ratio between DMP and RPM is adjusted according to the land use cover (FAO 2020).
5. Identification of the most likely land use change for the baseline scenario of the land use type in question. This can result in several consecutive changes in time, or a continuous change in time to represent increased land use intensity. The aim of this step is to match the SOC content measured in such an agricultural system.
6. The carbon inputs after land use change will be calculated according to scientific information regarding the carbon content of different crops and grasses, the turnover rate of grasses and tree materials, and the carbon input due to manure and other sources, as well as information provided by the farmer regarding the proposed land management.
7. The effects of the baseline scenario management practices on soil organic carbon are modelled and compared to the soil organic carbon content under the proposed improved management. Projections include the effects of a changing climate.

Further information on the use of climate scenarios can be found in chapter 4.4.2.5 of this document.

Data for model initialization and land use change initialisation can be taken from the WoSIS database of soil profiles (Batjes et al., 2019). This database does not include information on land cover, it can therefore be supplemented with information on land cover provided by the European Space Agency (Malinowski et al. 2020). In the case that the required data is not present in WoSIS, data is to derive from scientific literature, relating to the defined scenarios. If this data are not found, soil samples shall be collected and analysed from these two systems.

4.4.2.4 Model Validation

Model validation consists of two parts: calculation of the model uncertainty and bias calculation. The model uncertainty calculation is carried out using a Bayesian approach, followed by a Markov Chain Monte Carlo simulation (Wikle & Berliner, 2007), which is then used to calculate the 95% confidence interval around the model estimate. To define the probability density function limits are set on the range of values that a parameter may have. Whenever available, the mean and standard deviations related to a parameter’s measurement will be used to build its probability density function. When not available, a probability density function will be established for each factor that reflects the confidence in the obtained value by first establishing the possible maximum and minimum values, and then adjusting the probability for each value accordingly. This results in a flatter probability density function for variables for which there is lower confidence, and sharper probability density function when observed data are very accurate and precise.

Equation 1

$$U = 1{,}96 * sd\left(SOC_{PS,m,A,t} - SOC_{BS,m,A,t}\right)$$

$$= 1{,}96 * sqrt\left[var\left(SOC_{PS,m,A,t} - SOC_{BS,m,A,t}\right)\right]$$

$$= 1{,}96 * sqrt\left[var\left(SOC_{PS,m,A,t}\right) + var\left(SOC_{BS,m,A,t}\right) - 2 * cov(SOC_{PS,m,A,t}, SOC_{BS,m,A,t})\right]$$

Where:

U	= Model uncertainty $(t\ SOC)$
$SOC_{PS,m,A,t}$	= Modelled soil organic carbon for the project scenario in the project area at time t $(t\ SOC)$
$SOC_{BS,m,A,t}$	= Modelled soil organic carbon for the baseline scenario in the project area at time t $(t\ SOC)$

The model bias indicates the average tendency of the model to over- or underestimate the carbon storage potential as well as the accuracy of the model. Two measures of model accuracy will be used during validation: the root-squared mean error (RMSE) and the model efficiency (EF). These will be calculated for each climatic zone. The RMSE is calculated as demonstrated in Equation 2:

Equation 2

$$RMSE \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}}$$

Where:

$RMSE$	= root-squared mean error $(dimensionless)$
$\hat{y}_i$	= - predicted variable $(t\ SOC/ha)$
y_i	= observed variable$(t\ SOC/ha)$
n	= total number of observations

Lower values for the root-square mean error are preferable and indicative that large errors did not occur.

Model efficiency is calculated as demonstrated in Equation 3, based on Nash et al. (1970):

Equation 3

$$ME = 1 - \frac{(SUM((\hat{y} - y)^2)}{(SUM\left(y - \frac{\sum y}{n}\right)^2)}$$

Where:

ME = model efficiency $(value\ between\ 0 - 1)$

$\hat{y}$ = predicted variable $(t\ SOC/ha)$

y = observed variable $(t\ SOC/ha)$

n = total number of observations $(0 - \infty)$

The model efficiency value can lie between 0 and 1. Higher values are preferable as they indicate higher model efficiency.

To calculate RMSE and ME, a validation set (independent from the calibration set) should be obtained from peer-reviewed sources for each new management practice introduced in the project scenario. This validation set must include measurements for organic soil carbon stock or measurements necessary to calculate carbon stock, as well as one or several of the new management practices, whenever possible, compared with a control treatment. The RMSE and ME shall be calculated individually for each management practice, and a mean RMSE and ME included all practices implemented in the new scenario shall be reported. Calibration of the validation set will follow the same steps laid out in the previous section.

Model validation shall be performed with the start of the project period.

4.4.2.5 Climate Scenarios

The applied model shall be run with a minimum of two different climate scenarios. The chosen data sets shall depict scenarios representing the extremes of climate forcing. This approach demonstrates the possible range of sequestered carbon. Following information shall be provided in the Project Description:

- Justification of the choice of the climate scenarios
- Documentation on the application process
- Short description of the main scenario characteristics.
- Description on how model uncertainty is addressed with the applied scenarios

Further information on climate scenarios and specific examples can be found at:
https://www.ipcc.ch/site/assets/uploads/2018/03/emissions_scenarios-1.pdf

The document also provides an overview of scenario families. An extreme scenario can be picked form the A1 family (among the highest) and one from the B2 family (among the lowest).

4.5 Estimation of Leakage

Increased emissions of greenhouse gases outside the project boundaries, resulting from project activities, is defined as leakage. Leakage can arise through different causes. A common source is the additional application of manure originating from outside the project area. Declining productivity in the project area due to a spatial shift of crop production to an area beyond the project boundary is also considered as leakage and must be deducted if a defined threshold of 10% is reached. Crop yield is naturally varying from year to year, due to multiple reasons. The causes are not always traceable to 100%. If the farmer can't justify a yield decline through obvious reasons (e.g. drought or pests) the amount of issuable credits decreases to the farmers disadvantage. Hence a yield variation up to 10% is likely and shall not affect the amount of issuable credits.

4.5.1 Leakage caused by the application of manure

A deduction shall be implemented if additional manure is applied within the project area, that exceeds the use of manure in the baseline scenario and originates from outside the spatial project boundary. The resulting emissions shall be quantified according to Equation 4. The resulting emissions shall not be deducted if the manure was produced within the project boundary. Following assessment approach was adopted and modified based on the VSC Methodology *"VM0042 Methodology for improved agricultural land management" (2020)*.

Equation 4

$$L_{A,t} = M_{Manure,A,t} \times C_{Manure,A,t} \times 0{,}12 \times \frac{44}{12}) -$$

Where:

$L_{A,t}$	= Leakage in year t in project area A($t\ CO_2 eq$)
$M_{Manure,A,t}$	= Mass of manure applied as fertilizer on the project area A from livestock in year t $(tonnes)$
$C_{Manure,PA,t}$	= Carbon content of manure applied as fertilizer on the project area from livestock in year t
$0{,}12$	= Fraction of manure carbon expected to remain in the soil by the end of the project term (Maillard and Angers, 2014)

4.5.2 Leakage caused by productivity decline

Referring to the applicability conditions of this methodology, in areas within the project boundary, yield shall be maintained or increased. Project designs that knowingly lead to a reduced yield are not permitted. Generally, the project area remains in agricultural use and serves as a source of income for the farmer throughout the project period. Thus, it is not expected that management practices, resulting in a yield-related leakage risk, will be implemented and maintained.

Nevertheless, yield must be monitored throughout the project time. In the event of a project-related productivity decline greater than the expected annual variance, it must be assumed that the productivity decline will be compensated by areas outside the project spatial boundary. Unless the project proponent provides evidence that the productivity changes are caused by factors unrelated to the project activities, the spatial shift must be accounted for as leakage. Considerable factors avoiding deductions include inter alia unfavourable weather conditions or pest infestations.

The final monitoring report must demonstrate that yield productivity has not declined more than in an expected annual variance during the project period. If, contrary to expectations, there is a decline in crop yields, it must be examined whether this occurred only temporarily or permanently.

The continuity of yield during the project period is demonstrated by proving that the average productivity has not declined by more than 10% compared to the baseline scenario. Years with reduced yield that are verifiably not the result of project activities are excluded from the calculation.

4.6 Total emissions and removals

The overall project balance is considered as positive if the sum of sequestered and avoided carbon emissions lies above 0. The project is assigned a negative balance if the sum of sequestered and avoided carbon emissions lies below 0.

4.6.1 Estimating total removals

Creditable carbon sequestration is calculated as the net change of soil organic carbon between the project and the baseline scenario, attributable to project activities, as shown in Equation 5.

Equation 5

$$\varDelta SOC_{A,t} = ((\Delta SOC_{PS,m,A,t} - \Delta SOC_{PS,m,A,t-1}) - (\Delta SOC_{BS,m,A,t} - \Delta SOC_{BS,m,A,t-1})$$

Where:

$\varDelta SOC_{A,t}$ = Total soil organic carbon sequestered in the project area at time t $(t\ SOC)$

$\Delta SOC_{PS,m,A,t}$ = Modelled soil organic carbon for the project scenario in the project area at time t $(t\ SOC)$

$\Delta SOC_{BS,m,A,t}$ = Modelled soil organic carbon for the baseline scenario in the project area at time t $(t\ SOC)$

Soil organic carbon stocks as well as organic carbon sequestered by trees and shrubs shall be converted to a CO_2equivalent by multiplying with a conversion factor of $\frac{44}{12}$. Exemplified in Equation 6, with the conversion from SOC to CO2eq.

Equation 6

$$\Delta CO_{2_{soil_{A,t}}} = \Delta SOC_{A,t} \times \frac{44}{12}$$

Where:

$\Delta CO_2 soil_{A,t}$ = Total amount of sequestered CO_2 in the soil of the project area A at Time t $(t\ CO_2)$

$\Delta SOC_{A,t}$ = Total soil organic carbon sequestered in the project area A at time t (t SOC)

$\frac{44}{12}$ = C to CO_2 conversion factor (molecular mass ratio)

The credible carbon benefits are estimated by the sum of all emission reductions, consisting of the total amount of soil organic carbon (converted to carbon equivalents CO2eq), the total amount of sequestered carbon in trees and the total amount of sequestered carbon in shrubs.

Equation 7

$$\Delta CO_{2,rem,A,t} = \Delta CO_{2_{soil_{A,t}}} + \Delta CO_{2_{AF_{A,t}}} + \Delta CO_{2_{SHR_{A,t}}}$$

Where:

$\Delta CO_{2,rem,A,t}$ = Sum of sequestered carbon in the project area A in year t $(t\ CO_2)$

$\Delta CO_{2_{soil_{A,t}}}$ = Total amount of sequestered CO_2 in the soil of the project area A at time t $(t\ CO_2)$

$\Delta CO_{2_{AF_{A,t}}}$ = Total amount of sequestered CO_2 in trees in the project area A at time t $(t\ CO_2)$

$\Delta CO_{2_{SHR_{A,t}}}$ = Total amount of sequestered CO_2 in shrubs in the project area A at time t $(t\ CO_2)$

4.6.2 Estimating total emission reductions

The total amount of GHG emissions reductions is estimated by the sum of the total amount of carbon dioxide emissions, methane emissions, nitrous oxide emissions and fossil fuel emissions.

Equation 8

$$ER_{A,t} = \left(\Delta CO_2 eq_{CH_4 A,t} + \Delta CO_2 eq_{N_2O,A,t} + \Delta CO_{2,FF,A,t}\right)$$

Where:

$ER_{A,t}$ = Emission reductions in year t for the project area A $(t\ CO_2eq)$

$\Delta CO_{2,FF,A,t}$ = Reduction of carbon dioxide emissions from fossil fuels in the project area A in year t $(t\ CO_2)$

$\Delta CO_2eq_{CH_4A,t}$ = Sum of methane emission reductions in the project area A in year t converted into CO_2 equivalents $(t\ CO_2eq)$

$\Delta CO_2eq_{N_2O,A,t}$ = Nitrous oxide emission reductions in project area A in year t converted into CO_2 equivalents $(t\ CO_2eq)$

5. Baseline and Project Methodology

The baseline scenario represents emissions and/or removals that would have occurred in the absence of a project. It serves as a quantitative reference and provides the basis for comparison with project emissions and/or removals as well as with the temporal evolution of ecosystem co-benefits.

5.1 Definition of baselines and project scenario

The project proponent must define baseline values or scenarios for the soil modelling, CO2eq emission balance and co-benefits as well as the definition of the project scenario. The following sections outline the approach for each of these.

5.1.1 Definition of the Baseline Scenario for Soil Modelling

To calculate the SOC balance, two different approaches can be applied to define the baseline scenario.

Approach 1:

The relevant baseline scenario is the continuation of the historical land management practices that were followed in the 3 proceeding years before the project start date. The minimum specifications of management practices required for setting the baseline are outlined in Chapter 4.1, Table 3.

Approach 2:

The baseline scenario is defined with the support of the CDM A/R Methodological tool *“Combined tool to identify the baseline scenario and demonstrate additionality in A/R CDM project activities”.*

5.1.2 Definition of the Project Scenario for Soil Modelling

The project scenario is also defined at the project start and is a hypothetical reference case that best represents the conditions most likely to occur in the presence of the proposed GHG project. The relevant data is listed in the table below and shall be recorded in the project documentation as the baseline scenario.

5.1.3 Definition of the Baseline Values for the CO2eq Emission Balance

The baseline values for the CO2eq Emission Balance are calculated as an average of obtainable values from the preceding years. Outliers are to be taken into account and can be removed from the average values if necessary. These adjustments shall be justified and documented.

5.1.4 Definition of the Baseline Values for the Co-Benefits

The baseline for monitoring Co-Benefits is set depending on the assessed parameters. The details shall be part of the project description and thus of the project documentation.

5.2 Data collection for the Baseline and the Project Scenario

The data listed in the tables below is recorded in the project documentation. The lists shall be complemented and adjusted for each project in accordance with the monitored Co-Benefits.

Table 6: Data collection for the baseline scenario

Data to be collected and recorded to define the baseline scenario				
Data/ Parameter	**Unit**	**Description**	**Recording frequency**	**Source**
SOC_{BS}	tC/ha	SOC to a depth of 30 cm at equilibrium for stratum i	Project start	Soil samples, peer reviewed data, open source platforms
A_{crop}	hectare	Size of baseline area under cropland	Project start	remote sensing
A_{grass}	hectare	Size of baseline area under grassland	Project start	remote sensing
fym_inputs	tonnes /hectare	Total amount of manure input in parcel i	Project start, monitoring	Farmer
c_inputs	tonnes/mont	Plant residues left	Project start	Farmer

	h	on the field per month (calculated from baseline production) in parcel i		
PRO_i	tonnes/ha/month	Baseline production in parcel i per month	Project start	Farmer
$temp$	∅°C	Average temperature per month (an equilibrium run is performed with historic data from a 30-year reference period before project start, representative for the project area)	Project start	data provided by national weather services
$precip$	∅mm/month	Average precipitation per month (an equilibrium run is performed with historic data from a 30-year reference period before project start, representative for the project area)	Project start	data provided by national weather services
$evap$	∅mm/month	Average evapotranspiration per month (an equilibrium run is performed with historic data from a 30-year reference period before project start, representative for the project area)	Project start	data provided by national weather services
$DM_{t,i}$	kg dm/ha	Harvested annual dry matter in	Project start	Farmer

		stratum i		
$clay$	%	Clay content of parcel i	Project start	Soil sampling, regional or national soil maps, open-source platforms
$bare$	soil cover(Y/N)/ month	Soil cover in parcel i	Project start	Farmer & support through remote sensing
AF	hectare	Area size of agroforest in the project scenario	Project start	Farmer
(number)	dimensionless	number and species of trees in the project scenario	Project start	Farmer
DT	cm	diameter of trees at breast height	Project start	Farmer

Table 7: Data collection for the project scenario

Data to be collected and archived to define the project scenario				
Data/ Parameter	**Unit**	**Description**	**Recording frequency**	**Source**
SOC_{PS}	tC/ha	Soil organic carbon, to a depth of 30 cm, at equilibrium in the project scenario	Project start	Soil samples, peer reviewed data, open source platforms
A_{crop}	hectare	Size of project area under cropland in the project scenario	Project start	Remote sensing
A_{grass}	hectare	Size of project area under grassland in the project scenario	Project start	Remote sensing
fym_inputs	tonnes /hectare	Total amount of manure input in parcel i in the project scenario	Project start	Farmer

c_inputs	tonnes/month	Plant residues left on the field per month (calculated from project production) in stratum i	Project start	Farmer
PRO_i	tonnes/hectare/month	Project production in parcel i per month	Project start	Farmer
$temp$	∅°C	Average temperature per month	Project start	Data is derived from applied climate scenarios
$precip$	∅mm/month	Average precipitation per month	Project start	Data is derived from applied climate scenarios
$evap$	∅mm/month	Average evapotranspiration per month	Project start	Data is derived from applied climate scenarios
$DM_{t,i}$	kg dm/hectare	Harvested annual dry matter in parcel i in the project scenario	Project start	Farmer
$clay$	%	Clay content of parcel i in the project scenario	Project start	Soil sampling, regional or national soil maps, open-source platforms
$bare$	soil cover(Y/N)/month	Soil cover in parcel i in the project scenario	Project start	Farmer & support through remote sensing
AF	hectare	Area size of agroforestry in the project scenario	Project start	Farmer
(number)	dimensionless	number and species of trees in the project scenario	Project start	Farmer
DT	cm	diameter of trees at breast height	Project start	Farmer

5.3 Quantification of the Baseline and Project SOC

SOC values are assessed for all specified parcels (stratification is performed as described in chapter 4.1). As outlined in Equation 9 total SOC for a given time is the sum of stocks in each parcel multiplied by the respective parcel area. The model uncertainty is assessed as described in chapter 4.4.2.4. To follow the principle of conservativeness, the uncertainty ratio is to be deducted from the calculated removals. Units "BS" are replaced with "PS" for equations referring to the project scenario.

Equation 9

$$\Delta SOC_{BS,m,A,t} = \sum_{i=1}^{i} \left(SOC_{BS,m,i} \times A_i\right)$$

Where:

$\Delta SOC_{BS,m,A,t}$ = Modelled soil organic carbon for the baseline scenario in the project area A at time t $(t\,SOC)$

$SOC_{BS,m,i}$ = Modelled soil organic carbon per hectare in sample unit (stratum) i $(t\,SOC\,/ha)$

A_i = Area of sample unit (stratum) i (ha)

On-site soil organic carbon measurements are typically accompanied with higher investment costs. These can turn into financial obstacles affecting primarily small community-based projects and may prevent participating in the certification process. Taking these circumstances into account, this methodology incorporates adaptable approaches to assess initial soil organic carbon. The most accurate approach shall be selected based on financial viability.

Approach 1:

An adequate number of soil samples is analysed to determine initial SOC as input data for the applied model. Sampling analysis shall be done according to accepted scientific methods (see section: Soil Data). Deviations from the suggested method shall be documented adequately and reviewed by the project proponent and the certifying body.

Approach 2:

Soil data is retrieved from open-source soil data platforms or peer reviewed literature, under consideration of the criteria listed in chapter 4.3. Evidence for data applicability for the project area must be provided and validated by the project proponent and is reviewed by the certifying body.

As for the baseline scenario, the two different approaches for the SOC assessment can be followed to assess SOC in the project scenario. If the method is changed throughout the project period, comparability and conservativeness must be ensured.

5.4 Modeling soil organic carbon stocks in the baseline and the project scenario

Equilibrium soil organic carbon stocks are estimated using a suitable carbon model, accepted in scientific publications, and validated for the specific project area. The present methodology is designed for the use of RothC. Equilibrium carbon stocks are modelled for a soil depth of 30 cm. Once the soil properties have been obtained, model initialization is performed through an equilibrium run to get the breakdown of the soil into its components. The model is run in an inverse mode over 500 years to reach an equilibrium that matches the expected SOC value from the soil samples. The model then returns the breakdown of the soil into compartments that are necessary to estimate the current and future SOC values. It must be documented from which sources the model input data originate and how it is analysed.

5.5 Estimation of Changes in Carbon Stocks in Woody Biomass

If the assessment of above and below ground woody biomass is included within the project boundary, the project proponent shall follow the CDM A/R Tool "*Estimation of carbon stocks and change in carbon stocks of trees and shrubs"* in A/R CDM "*project activities and Simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under the clean development mechanism implemented on grasslands or croplands"* AR-AMS0001e.

6. Monitoring Methodology

The monitoring methodology serves as a guide for data collection during the project period. A monitoring plan is elaborated for each project. The assessed values serve as input data for the reports, prepared by the project proponent and through the support of the farmer, by providing relevant data. It is archived and serves as a performance tracking tool. The data to be collected are presented below and are tailored to the present methodology and thus to the use of the RothC model.

6.1 Reporting

Each reporting round serves as a tool to quantify and document the effects of project activities on:

- CO2eq emission changes (CO_2, $CH_4$and N_2O)
- Stock changes of soil organic carbon and carbon sequestration in woody perennials
- Co-Benefits

As outlined in previous chapters, this can be done using ground truth data and by applying models. If applicable, the approaches can be supported by the implementation of default values. The outcome of each reporting round is a document, tailored to the specific characteristics of the site and must include a description of the data assessment procedures. The documentation shall contain:

- Detailed description of the land management changes implemented
- Map of stratification
- Sampling approach (if applicable)
- Values of monitored parameters
- Documentation of measurement techniques

If on site measurements are included in a monitoring round, it must be ensured that the applied equipment is calibrated and measuring methods meet scientific standards, as outlined in the previous chapters. Furthermore, the project proponent shall ensure that the methodology's applicability conditions are always met. All monitored values and issued reports must be documented electronically and kept archived for at least 5 years after the project period ends. If any parameters are used for the modelling process that are not listed in the parameter table the list must be amended and attached to the documentation. Data to be monitored for the monitoring methodology, hence for the reporting, is listed in the chapter below.

6.2 Data to be collected for the Monitoring Methodology

The data listed in the table below is recorded in the project documentation. The list shall be complemented and adjusted for each project in accordance with the monitored Co-Benefits.

Table 8: Data to be collected for the Monitoring Methodology.

Data to be collected and archived to define the monitoring methodology				
Data/ Parameter	**Unit**	**Description**	**Recording frequency**	**Source**
A_{crop}	hectare	Size of project area under cropland	For every reporting round	Remote sensing
A_{grass}	hectare	Size of project area under grassland	For every reporting round	Remote sensing
fym_inputs	tonnes /hectare	Total amount of manure input in parcel i	For every reporting round	Farmer
c_inputs	tonnes/month	Plant residues left on the field per month (calculated from project production) in parcel i	For every reporting round	Farmer
PRO_i	tonnes/hectare/month	Project production in parcel i per month	For every reporting round	Farmer
$DM_{t,i}$	kg dm/hectare	Harvested annual dry matter in parcel i in the	For every reporting round	Farmer
$bare$	soil	Soil cover in parcel i	For every	Farmer &

	cover(Y/N) /month		reporting round	support through remote sensing
AF	hectare	Area size of agroforestry	For every reporting round	Farmer
(number)	dimensionless	number and species of trees	For every reporting round	Farmer
DT	cm	diameter of trees at breast height	For every reporting round	Farmer

6.3 Co-Benefits

In the present methodology, a Co-Benefit is defined as a positive side effect on an ecosystem that is attributable to the application of sustainable land management practices.

Measuring and tracking Co-benefits allows an assessment of the effectiveness of applied land management practices and their impact.

The following parameters can be measured to track the development of co-benefits over the project period:

Vegetation Productivity (EVI)

Vegetation productivity refers to the spatial distribution and condition of vegetation cover within the project area (European Environmental Agency, 2022). It is assessed by the satellite-derived Enhanced Vegetation Index (EVI) which allows the quantification of vegetation greenness for any given field depending on the reflection rate of the electromagnetic spectrum. The assessment of the EVI is a common remote sensing method for the evaluation of agricultural land to track anthropogenic impacts on ecosystems (Gilabert et. al., 2017).

Water Retention (NDMI)

Water Stress is related to the plant-available water in soils which makes it an efficient stress indicator for plants. If the water availability in soils declines, plant growth and productivity are affected leading to the reduction of crop yields and soil functionality (Osakabe et. al., 2014). The detection of water stress is done by calculating the Normalized Difference Moisture Index (NDMI) (Jahangir and Arast, 2020).

Biodiversity (Cool Farm Tool)

Agrobiodiversity is defined by the variety and variability of living organisms such as animals, plants and microorganisms that influence the agricultural context. It can be differentiated between “planned biodiversity” including crops and livestock and “associated biodiversity” including soil microbes and fauna, weeds, herbivores, and carnivores. One option to assess the impact of farming practices on biodiversity is to apply the biodiversity methodology developed by Cool Farm Tool. The concept follows an evidence-based approach that quantifies how well agricultural practices support biodiversity at farm level (CFT, 2016). Additional parameters may be used to evaluate the extent to which the soil under investigation is capable of fulfilling its functions. The listed parameters and any additional parameters that are considered must comply with the following principles in order to meet all necessary monitoring requirements:

- The applied measurement method must meet scientific standards.
- The measurement method must be recorded and described in the project description.
- The assessment of the chosen parameters must be appropriate for the project area. (Feasibility is proven through scientific literature)
- The general approach must remain consistent throughout the project period or comparability must be maintained.
- A defined monitoring frequency, tailored to the Co-Benefit in question, must be in place before project start and documented in the project description
- Before the project starts, a baseline is defined as a reference component.

Further details on the proposed approaches can be found on the Climate Farmers website.

7. CO2eq Emission Balance

The CO2eq Emission Balance serves as tool to calculate major greenhouse gas emissions and emission reductions in a defined project area.

7.1 Quantification of Carbon Dioxide Emissions from Fossil Fuel Combustion

If carbon dioxide emissions from fossil fuels are included in the project boundary, annual monitoring shall be carried out. Relevant sources are vehicles such as trucks, tractors, etc. and mechanical equipment required for the land management. The baseline value used as a reference for comparison is calculated from an average of obtainable values from the preceding years. Outliers are to be taken into account and can be removed from the average values if necessary. These adjustments shall be justified and documented.

Equation 10

$$CO_{2,FF,A,t} = \sum_{i=1}^{i} EFF_{iA,t}$$

Where:

$CO_{2,FF,A,t}$ = Carbon dioxide emissions due to fossil fuels in the project area A in year t $(t\ CO_2)$

$EFF_{i,A,t}$ = Carbon dioxide emissions from fossil fuel combustion from type of fossil fuel i in project area A in year t $(t\ CO_2)$

i = type of fossil fuel

Carbon dioxide emissions from fossil fuel type i are estimated as in equation 11.

Equation 11

$$EFF_{i,A,t} = CFF_i \times EF_{CO_2,i}$$

Where:

$EFF_{i,A,t}$ = Carbon dioxide emissions from fossil fuel combustion from type of fossil fuel i in project area A in year t $(t\,CO_2eq)$

$CFF_{i,t}$ = Fossil fuel consumption of type i in year t $(liter)$

$EF_{CO_2,i}$ = Emission factor of fossil fuel type i $(factor)$

i = Type of fossil fuel Carbon dioxide emission reductions are estimated with equation 12.

Equation 12

$$\Delta CO_{2,FF,A,t} = (CO_{2,FF,A,t} - CO_{2,FF,A,t+1})$$

Where:

$\Delta CO_{2,FF,A,t}$ = Reduction of carbon dioxide emissions from fossil fuels in the project area A in year t $(t\,CO_2)$

$CO_{2,FF,A,t}$ = Carbon dioxide emissions from fossil fuels in the project area A in year t $(t\,CO_2)$

7.2 Quantification of methane emissions and removals

Methane is a powerful greenhouse gas that contributes significantly to climate change. Measured over a period of 100 years, its global warming potential is roughly 28-34 times higher than that of CO2 (EPA, 2022). Enteric fermentation caused by livestock, as well as general manure management are the two main contributors to methane production in agriculture systems. The present methodology follows the approach below to estimate methane emissions through enteric fermentation and manure deposition. It is adopted and adjusted from the "Methodology for improved agricultural land management VM0042" (2020) and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

7.2.1 Quantification of methane emissions through enteric fermentation

A variety of criteria, such as the type of digestive tract, age, weight of the animal, and the quality and quantity of the feed consumed are influencing the total amount of emissions caused by enteric fermentation (IPCC, 2006).

If livestock is present within the project boundaries, methane emissions must be monitored over the project period. In order to quantify total methane emissions originating from enteric fermentation, the type of livestock, the number of animals and the average grazing days throughout the year must be documented. The baseline value used as a reference for comparison is calculated from an average of obtainable values from the preceding years. Outliers are to be taken into account and can be removed from the average values if necessary. These adjustments shall be justified and documented. The emissions from livestock for a defined period are calculated using Equation 13.

Equation 13

$$CH_{4,ef,i,t} = \frac{1}{A_i \times 1000 \times 365} \times \sum_{l=1}^{L} (P_{l,i,t} \times D_{l,i,t} \times EF_{ent,l})$$

Where:

$CH_{4,ef,i,t}$ = Methane emission from livestock enteric fermentation ef in sample unit i in year t $(t\ CH_4)$

$P_{l,i,t}$ = Total number of grazing livestock of type l in sample unit i in year t $(head)$

$D_{l,i,t}$ = Grazing days per head in year t for each livestock type l in sample unit i $(days)$

$EF_{ent,l}$ = Enteric emission factor for livestock type l $(kg\ CH_4/(head \times year))$

1000 = kg per tonne

365 = days per year

A_i = Area of sample unit i

Peer reviewed published data may be used to assess the enteric emission factor $(EF_{ent,l})$ for livestock. Hence, suitable values could be retrieved from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 chapter 10 in Table 10.10 and Table 10.11. Depending on data availability, either a default parameter, as presented in the mentioned tables, or a value estimated from relevant measurements can be applied, following the Tier 2 approach outlined in the 2006 IPCC Guidelines. A default parameter is highly uncertain and should only be applied if relevant data is not available. The source of the emission factor must be recorded in the project description.

Reduction of methane emissions from enteric fermentation is estimated with equation 14 as followed:

Equation 14

$$CO_2eq_{CH_4ef,A,t} = \left(\sum_{i=1}^{i} CH_{4,ef,i,t} - \sum_{i=1}^{i} CH_{4,ef,i,t+1}\right) \times GWP_{CH_4}$$

Where:

$CO_2eq_{CH_4ef,A,t}$ = Reduction of methane emissions from enteric fermentation in project area A in year t $(t\ CO_2)$

$CH_{4,ef,i,t}$ = Methane emissions from enteric fermentation in sample unit i in year t $(t\ CH_4)$

GWP_{CH_4} = Global warming potential for methane

7.2.2 Quantification of methane emissions through manure deposition

The approach for quantification of methane emissions through manure deposition is adopted and adjusted from the “Methodology for improved agricultural land management VM0042” (2020) and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The baseline value used as a reference for comparison is calculated from an average of obtainable values from the preceding years. Outliers are to be taken into account and can be removed from the average values if necessary. These adjustments shall be justified and documented.

Equation 15

$$CH_{4,md,i,t} = \frac{1}{10^6 \times A_i} \times \sum_{l=1}^{L} (P_{l,i,t} \times VS_{l,i,t} \times EF_{CH_4,md,l} \times D_{l,i,t})$$

Where:

$CH_{4,md,i,t}$ = Total amount of methane emissions due to manure deposition in year t in sample unit i $(t\ CH_4)$

$P_{l,i,t}$ =Total number of grazing livestock of type l in sample unit i in year t $(head)$

$EF_{CH_4,md,l}$ = Emission factor for methane emissions from manure deposition for livestock type l $(g\ CH_4/(kg\ volatile\ solids))$

$D_{l,i,t}$ = Grazing days per head in year t for each livestock type l in sample unit i $(days)$

$VS_{l,i,t}$ = Volatile solids per head per livestock type l in sample unit i in year t $(kg\ volatile\ solids/(head * day))$

10^6 = gram per tonne

A_i = Sample unit i in project area A $(hectare)$

l = Type of livestock

i = Sample unit

CO_2 equivalents for methane emissions caused by manure depositions are estimated by multiplying the total amount of methane emissions due to manure deposition with the global warming potential factor for methane.

Reduction of methane emissions from manure deposition is estimated with equation 16.

Equation 16

$$CO_2eq_{CH_4md,A,t} = (\sum_{i=1}^{i} CH_{4,md,i,t} - \sum_{i=1}^{i} CH_{4,md,i,t+1}) \times GWP_{CH_4}$$

Where:

$CO_2eq_{CH_4md,A,t}$ = Reduction of methane emissions from manure deposition in project area A in year t (CO_2eq)

$CO_2eq_{CH_4md,A,t}$ = Reduction of methane emissions from manure deposition in project area A in year t (CO_2eq)

$CH_{4,md,i,t}$ = Total amount of methane emissions from manure deposition in sample unit i in year t $(t\,CH_4)$

GWP_{CH_4} = Global warming potential of methane

= Reduction of methane emissions from manure deposition in project area A in year t (CO_2eq)

The total amount of methane emission reductions converted into CO_2eq for project area A in year t is estimated as followed:

Equation 17

$$\Delta CO_2eq_{CH_4A,t} = CO_2eq_{CH_4md,A,t} + CO_2eq_{CH_4ef,A,t}$$

Where:

$\Delta CO_2eq_{CH_4A,t}$ = Sum of methane emission reductions in the project area A in year t converted into CO_2 equivalents (CO_2eq)

$CO_2eq_{CH_4md,A,t}$ = Reduction of methane emissions from manure deposition in project area A in year t (CO_2eq)

$CO_2eq_{CH_4ef,A,t}$ = Reduction of methane emissions from enteric fermentation in project area A in year t $(t\,CO_2)$

A = Project Area $(hectare)$

i = Sample unit

7.3 Quantification of nitrous oxide emissions

This section presents methods and equations to estimate the total N_2O emissions of the project area. Nitrous oxide is produced naturally in soils through the processes of nitrification and denitrification. The amount of nitrous oxide emissions is strongly dependent on the availability of nitrogen in the soil. Hence, this methodology estimates anthropogenically-induced net Nitrogen additions to the project area and the resulting greenhouse gasses. Considered sources are:

- manure deposition
- synthetic N fertilizer
- organic N applied as fertilizer (manure, compost, sewage sludge, etc.)
- crop residues and N-fixing crops

The methodology utilizes terminology and a scientific approach presented in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories to calculate direct emissions of N_2O.

The baseline values used as reference for comparison are calculated from an average of obtainable values from the preceding years. Outliers are to be taken into account and can be removed from the average values if necessary. These adjustments shall be justified and documented.

7.3.1 Nitrous oxide emissions through manure deposition

Direct nitrous oxide emissions and emission reductions due to manure deposition are quantified by applying Equation 18 and Equation 19. The approach is adopted and adjusted from the “Methodology for improved agricultural land management VM0042” (2020) and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Equation 18

$$N_2O_{md,direct,i,t} = \left(\sum_{l=1}^{l} N_{manure,l,i,t} \times EF_{N_2O,md,l} \times \frac{44}{28}\right) / A_i$$

Equation 19

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

Where:

$N_2O_{md,direct,i,t}$	= Direct nitrous oxide emissions through manure deposition in sample unit i in year t $(t\ N_2O/unit\ area)$
$N_{manure,l,i,t}$	= Amount of nitrogen in manure and urine deposited on soils by livestock type l in sample unit i in year t $(t\ N)$
$P_{l,i,t}$	=Total number of grazing livestock of type l for sample unit i in year t $(head)$
Nex_l	= Average annual nitrogen excretion per head of livestock type l $(kg\ N/head/year)$
$F_{l,i,t}$	= Fraction of total annual nitrogen excretion for each livestock type l for sample unit i in year t that is deposited on the project area $(\%)$

$EF_{N_2O,md,l}$ = Emission factor for nitrous oxide from manure and urine deposited on soils by livestock type l ($\frac{kg\ N2O-N}{kg\ N}$)

Indirect nitrous oxide emissions due to manure deposition are quantified using Equation 20, Equation 21 and Equation 22.

Equation 20

$$N_2O_{md,indirect,i,t} = (N_2O_{md,vol,i,t} + N_2O_{md,leach,i,t})/A_i$$

Where:

Equation 21

$$N_2O_{md,vol,i,t} = N_{manure,l,i,t} \times Frac_{GASM} \times EF_{N,vol} \times \frac{44}{28}$$

Equation 22

$$N_2O_{md,leach,i,t} = N_{manure,l,i,t} \times Frac_{LEACH} \times EF_{N,leach} \times \frac{44}{28}$$

Where:

$N_2O_{md,indirect,i,t}$ = Indirect nitrous oxide emissions due to manure deposition in sample unit i in year t (tN_2O)

$N_2O_{md,vol,i,t}$ = Indirect nitrous oxide emissions produce from atmospheric deposition of N volatilized due to manure deposition for sample unit i in year t $(tN_2O/unit\ area)$

$N_2O_{md,leach,i,t}$ = Indirect nitrous oxide emissions from leaching and runoff of, in regions where leaching and runoff occurs, due to manure deposition for sample unit i in year t. $(tN_2O/unit\ area)$

$N_{manure,l,i,t}$ = Amount of nitrogen in manure and urine deposited on soils by livestock type l in sample unit i in year t $(t\ N)$

$Frac_{GASM}$ = Fraction of all organic N added to soils, N in manure and urine deposited on soils that volatilizes as NH_3 and NO_x $(dimensionless)$

$EF_{N,vol}$ = Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces $tN_2O-N/(t\ NH_3-N+NO_x\ -N\ volatilized)$

$Frac_{LEACH}$ = Fraction of all organic N applied to soils and N in manure and urine Deposited on soils that is lost through leaching and runoff, in regions where leaching occurs. $(dimensionless)$

$EF_{N,leach}$ = Emission factor for nitrous oxide emissions from leaching and runoff $(t\ N_2O - N/tN\ leached\ and\ runoff)$

A_i = Area of sample unit i

l = Type of livestock

i = Sample unit

If nitrous oxide emissions caused by manure deposition are included in the project boundary the respective carbon equivalents are estimated with the equations below.

Equation 23

$$\Delta N_2O_{md,A,t} = \sum_{i=1}^{i} N_2O_{md,direct,i,t} + \sum_{i=1}^{i} N_2O_{md,indirect,i,t}$$

Where:

$\Delta N_2O_{md,A,t}$ = N_2O emissions due to manure deposition in project area A inyear t $(t\ N_2O)$

$N_2O_{md,direct,i,t}$ = Direct nitrous oxide emissions through manure deposition in sample unit i in year t (tN_2O)

$N_2O_{md,indirect,i,t}$ = Indirect nitrous oxide emissions due to manure deposition for sample unit i in year t (tN_2O)

GWP_{N_2O} = Global warming potential for nitrous oxide

Reduction in nitrous oxide emissions from manure depositions are estimated according to Equation 23

Equation 24

$$CO_2eq_{N_2O,md,A,t} = (\Delta N_2O_{md,A,t} - \Delta N_2O_{md,A,t+1}) \times GWP_{N_2O}$$

Where:

$CO_2eq_{N_2O,md,A,t}$ = Reduction in nitrous oxide emissions from manure deposition in project area A in year t $(t\ CO_2)$

$\Delta N_2O_{md,A,t}$ = N_2O emissions due to manure deposition in project area A in year t (tCO_2eq)

GWP_{CH_4} = Global warming potential of methane

7.3.2 Nitrous Oxide Emissions through Fertilization

Direct nitrous oxide emissions from nitrogen fertilization can be estimated using Equation 25. The approach is adopted from the A/R Methodological tool "Estimation of direct nitrous oxide emission from nitrogen fertilization"

Equation 25

$$\Delta N_2O_{F,A,t} = (F_{SN,t} + F_{ON,t}) \times EF_1 \times MW_{N_2O}$$

Where:

Equation 26

$$F_{SN,t} = \sum_i^I M_{SFi,t} \times NC_{SF,i} \times (1 - Frac_{GASF})$$

Equation 27

$$F_{ON,t} = \sum_i^I M_{OF,j,t} \times NC_{OF,j} \times (1 - Frac_{GASM})$$

Where:

$\Delta N_2O_{F,A,t}$	= Direct N_2O emissions as a result of nitrogen application in project area A in year t $(t\ CO_2eq)$
$F_{SN,t}$	= Mass of synthetic fertilizer nitrogen applied adjusted for volatilization as NH_3 and NH_x $(t\ N\ in\ year\ t)$
$F_{ON,t}$	= Mass of organic fertilizer nitrogen applied adjusted for volatilization as NH_3 and NH_x $(t\ N\ in\ year\ t)$
EF_1	= Emission factor for direct nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments and crop residues
MW_{N_2O}	= Ratio of molecular weights of N_2O and N $(\frac{44}{28})$ $((t - N_2O)/(t - N))$
$M_{SFi,,t}$	= Mass of synthetic fertilizer type i applied in year t $(tonnes\ in\ year\ t)$
$M_{OF\,j,,t}$	= Mass of organic fertilizer type j applied in year t $(tonnes\ in\ year\ t)$
NC_{SFi}	= Nitrogen content of synthetic fertilizer type i applied $(t\ N/\ t\ fertilizer)$
$NC_{OF\,j}$	= Nitrogen content of organic fertilizer type j applied $(t\ N/\ t\ fertilizer)$
$Frac_{GASF}$	= Fraction that volatilises as NH_3 and NO_x for synthetic fertilizers $(dimensionless)$
$Frac_{GASM}$	= Fraction that volatilises as NH_3 and NO_x for organic fertilizers, $(dimensionless)$

i	= Number of synthetic fertilizer types $(dimensionless)$
j	= Number of organic fertilizer types $(dimensionless)$

The described method requires the farmer to monitor the mass of synthetic fertilizer type i applied in year t and the mass of organic fertilizer type j applied in year t. The emission factor (EF) is a country-specific value that shall be selected based on peer reviewed data. If no data is available the default value, suggested by the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories in chapter 11 "N_2O Emissions from managed soils, and CO_2 emissions from lime and urea application".

Reductions of nitrous oxide emissions from fertilizer use are estimated according to Equation 28.

Equation 28

$$CO_2eq_{N_2O,F,A,t} = (\Delta N_2O_{F,A,t} - \Delta N_2O_{F,A,t+1}) \times GWP_{N_2O}$$

Where:

$CO_2eq_{N_2O,F,A,t}$	= Reductions of nitrous oxide emissions from fertilizer use in project area A in year t (tCO_2eq)
$\Delta N_2O_{F,A,t}$	= Direct N_2O emissions as due to nitrogen application in project area A in year t $(t\,CO_2eq)$
GWP_{N_2O}	= Global warming potential for nitrous oxide

7.3.3 Nitrous Oxide Emissions through N-Fixing Species

Nitrous oxide emissions and emission reductions in the crediting period through n-fixing species are quantified with Equation 29, Equation 30 and Equation 31. The approach is adopted and adjusted from the "Methodology for improved agricultural land management VM0042" (2020) and the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Equation 29

$$\Delta N_2O_{Nfix,A,t} = (NFS_{t,A} \times EF_2 \times MW_{N_2O})$$

Where:

$\Delta N_2O_{Nfix,A,t}$	= Amount of nitrous oxide emissions in the accountable years due to the use of N-fixing species in project area A in year t (tCO_2eq)
$NFS_{t,A}$	= Amount of N-fixing species (above and below ground) returned to soils in year t in project area A $(tonnes)$.
EF_2	= Emission factor for nitrous oxide emissions from N-fixing species.

MW_{N_2O} = Ratio of molecular weight of N_2O to molecular weight of N ($\frac{44}{28}$)

The baseline value for the amount of N-fixing species (above and below ground) returned to soils is calculated as followed:

Equation 30

$$NFS_{t,A} = \sum_{i=1}^{i}(\sum_{g=1}^{n} DM_{g,i,t} \times N_{cont,g})$$

Where:

$NFS_{t,A}$ = Amount of N-fixing species (above and below ground) returned to soils in year t in project area A $(tonnes)$

$DM_{g,i,t}$ = Annual dry matter (above and below ground), N-fixing species g returned to soils for sample unit i in year t $(tonnes\ of\ dm)$

$N_{cont,g}$ = Fraction of N in dry matter for N-fixing species g $(t\ N/t\ dm)$

g = Type of N-fixing species

i = sample unit

Reduction of nitrous oxide emissions due to n-fixing species are estimated as in Equation 31

Equation 31

$$CO_2eq_{N_2o,Nfix,A,t} = (\Delta N_2O_{Nfix,A,t} - \Delta N_2O_{Nfix,A,t+1}) \times GWP_{N_2O}$$

Where:

$CO_2eq_{N_2o,Nfix,A,t}$ = Nitrous oxide emission reduction from nitrification/denitrification in year t in the project area A in year t (CO_2eq)

$\Delta N_2O_{Nfix,A,t}$ = Nitrous oxide emission from nitrogen inputs in project area A in year t (CO_2eq)

A = Project Area

The total amount of nitrous oxide emission reductions converted into CO_2eq for project area A in year t is estimated as followed:

Equation 32

$$\Delta CO_2eq_{N_2O,A,t} = CO_2eq_{N_2O,md,A,t} + CO_2eq_{N_2O,F,A,t} + CO_2eq_{N_2o,Nfix,A,t}$$

Where:

$\Delta CO_2eq_{N_2O,A,t}$ = Total amount of nitrous oxide emission reductions converted into CO_2eq in project area A in year t (t CO_2eq)

$CO_2eq_{N_2O,md,A,t}$ = Reduction in nitrous oxide emissions from manure deposition in project area A in year t ($t\ CO_2eq$)

$CO_2eq_{N_2O,F,A,t}$ = Reductions of nitrous oxide emissions from fertilizer use in project area A in year t (tCO_2eq)

$CO_2eq_{N_2o,Nfix,A,t}$ = Nitrous oxide emission reduction from nitrification/denitrification in year t in the project area A in year(CO_2eq)

7.4 Data to be collected for the CO2eq Emission Balance

Table 9: List of data to be collected for the CO2eq Emission Balance

List of data to be collected for a project to elaborate a CO2eq Emission Balance				
Data/Parameter	**Unit**	**Description**	**Source**	**Recording frequency**
CF_i	liter	Fossil fuel consumption of type i	Documented by the Farmer	Annually
$P_{l,i,t}$	dimensionless	Number of grazing livestock of type l in sample unit i in the crediting period t	Documented by the Farmer	Annually
$D_{CP,l,i,t}$	dimensionless	Grazing days per head in the crediting period years t for each livestock type l in sample unit i	Documented by the Farmer	Annually
A_i	hectare	Area of sample unit i, where rotational grazing is performed in the crediting period	Remote sensing	Annually
$M_{SFi,CP,t}$	tonnes in year t	Mass of synthetic fertilizer type i applied in the accountable years	Documented by the Farmer	Annually
$M_{OFj,CP,t}$	tonnes in year t	Mass of organic fertilizer type j applied	Documented by the Farmer	Annually
$NFS_{CP,i}$	tonnes in year t	Amount of N fixing species (above and below ground) returned to soils in the crediting period in sample unit i	Documented by the Farmer	Annually

$DM_{g,CP,i,t}$	tonnes	Annual dry matter (above and below ground), N-fixing species g returned to soils wfor sample unit i in the crediting period	Documented by the Farmer	Annually
g		Type of N-fixing species	Documented by the Farmer	Annually
A_i	hectare	Area of sample unit i, where synthetic nitrogen fertilizer is applied in the crediting period	Documented by the Farmer	Annually

8 Total amount of issuable CO2eq reduction and CO2eq removal credits

Issuable CO2eq reduction credits for a specific project are calculated with Equation 33. Leakage (if applicable) and the defined buffer are deducted from the total amount of calculated CO2eq emission reductions.

Equation 33

$$IC_{reductions} = (ER_{A,t} - L_{A,t}) * (1 - buffer)$$

Where:

$IC_{reductions}$ = Issuable CO2eq reduction credits for a specific project $(t\ CO_2eq)$

$ER_{A,t}$ = Emission reductions in year t for the project area A $(t\ CO_2eq)$

$L_{A,t}$ = Leakage in year t in project area A$(t\ CO_2eq)$

$buffer$ = Pool of certificates, serving as a security for project permanence $(t\ CO_2eq)$

Issuable CO2eq removal credits for a specific project are calculated with Equation 34. Uncertainty and defined buffer are deducted from the total amount of calculated CO2eq emission removals.

Equation 34

$$IC_{removals} = \left(\Delta CO_{2,rem,A,t} - U * \frac{44}{12}\right) * (1 - buffer)$$

Where:

$IC_{removals}$ = Issuable CO2eq removal credits for a specific project $(t\ CO_2eq)$

$\Delta CO_{2,rem,A,t}$	= Sum of sequestered carbon in the project area A in year t $(t\ CO_2)$
U	= Model uncertainty $(t\ SOC)$
$buffer$	= Pool of certificates, serving as a security for project permanence $(t\ CO_2eq)$

9. Required input data

Data/Parameter	A
Unit	ha
Data source	on site measurement or remote sensing
Description/ Comments	size of total project area
Equation	Equation 15, Equation 18,

Data/Parameter	$RMSE$
Unit	dimensionless
Data source	Calculated with Equation 2
Description/ Comments	Root-squared mean error
Equation	Equation 2

Data/Parameter	$\hat{y}$
Unit	$t\ SOC/ha$
Data source	predicted variable based on the guidance of the present methodology

Description/ Comments	Predicted variable
Equation	Equation 2, Equation 3

Data/Parameter	y
Unit	$t\,SOC/ha$
Data source	Open-source data base (such as WoSiS) or derived from soil samples
Description/ Comments	Observed variable
Equation	Equation 2, Equation 3

Data/Parameter	ME
Unit	$Value\ between\ 0-1$
Data source	Calculated with equation 2
Description/ Comments	Model efficiency
Equation	Equation 3

Data/Parameter	$L_{A,t}$
Unit	$t\,CO_2eq$
Data source	Estimated with Equation 4
Description/ Comments	Leakage in year t in project area A

Equation	Equation 4, Equation 8, Equation 33

Data/Parameter	$M_{Manure,A,t}$
Unit	tonnes
Data source	Documentation provided by Farmer
Description/ Comments	Mass of manure applied as fertilizer on the project area from livestock l in year t
Equation	Equation 4

Data/Parameter	$C_{Manure,PA,t}$
Unit	tonnes
Data source	Scientific paper
Description/ Comments	Carbon content of manure applied as fertilizer on the project area from livestock type in year t
Equation	Equation 4

Data/Parameter	$\Delta SOC_{A,t}$
Unit	$t\,SOC$
Data source	estimated with Equation 5
Description/ Comments	Total soil organic carbon sequestered in the project area A at time t
Equation	Equation 5, Equation 6

Data/Parameter	$SOC_{BS,m,A,t}$
Unit	$t\ SOC$
Data source	calculated through $SOC_{BS,m,i}\ and\ A$
Description/ Comments	Modelled soil organic carbon for the baseline scenario in the project area A at time t
Equation	Equation 1, Equation 5, Equation 9

Data/Parameter	$\Delta SOC_{PS,m,A,t}$
Unit	$t\ SOC$
Data source	calculated through $SOC_{PS,m,i}\ and\ A$
Description/ Comments	Modelled soil organic carbon for the project scenario in the project area A at time t
Equation	Equation 5

Data/Parameter	$\Delta CO_{2\,soil_{A,t}}$
Unit	$t\ CO_2$
Data source	Estimated with Equation 6
Description/ Comments	Total amount of sequestered CO_2 in the soil of the project area A at time t $(t\ CO_2)$

Equation	Equation 6, Equation 7

Data/Parameter	$\Delta CO_{2,rem,A,t}$
Unit	$t\ CO_2$
Data source	Estimated with Equation 7
Description/ Comments	Sum of sequestered carbon in the project area A in year t
Equation	Equation 7, Equation 34

Data/Parameter	$\Delta CO_{2_{AF_{A,t}}}$
Unit	$t\ CO_2$
Data source	Estimated according to CDM A/R Tool "*Estimation of carbon stocks and change in carbon stocks of trees and shrubs*"
Description/ Comments	Total amount of sequestered CO_2 in trees in the project area A at time t
Equation	Equation 7

Data/Parameter	$\Delta CO_{2_{SHR_{A,t}}}$
Unit	$t\ CO_2$
Data source	Estimated according to CDM A/R Tool "*Estimation of carbon stocks and change in carbon stocks of trees and shrubs*"

Description/ Comments	Total amount of sequestered CO_2 in shrubs in the project area A at time t
Equation	Equation 7

Data/Parameter	$\Delta CO_2eq_{CH_4A,t}$
Unit	$t\ CO_2eq$
Data source	Estimated with Equation 17
Description/ Comments	Sum of methane emission reductions in the project area A in year t converted into CO_2 equivalents
Equation	Equation 8, Equation 17

Data/Parameter	$\Delta CO_{2,FF,A,t}$
Unit	$t\ CO_2$
Data source	Estimated with Equation 12
Description/ Comments	Reduction of carbon dioxide emissions from fossil fuels in the project area A in year t Equation
Equation	Equation 8, Equation 12

Data/Parameter	$ER_{A,t}$
Unit	$t\ CO_2eq$
Data source	Estimated with Equation 7

Description/ Comments	Emission reductions in year t for the project area A $(t\ CO_2\,eq)$
Equation	Equation 8, Equation 33

Data/Parameter	U
Unit	$t\ SOC$
Data source	Calculated with Equation 1
Description/ Comments	Modell uncertainty
Equation	Equation 1, Equation 5, Equation 34

Data/Parameter	$\Delta SOC_{BS,m,i}$
Unit	$t\ SOC$
Data source	modelled
Description/ Comments	Modelled soil organic carbon per hectare in sample unit (parcel) i in the baseline scenario
Equation	Equation 9

Data/Parameter	$SOC_{PS,m,i}$
Unit	$t\ CO_2eq/ha$
Data source	modelled

Description/ Comments	Modelled soil organic carbon per hectare in sample unit (stratum) i in the project scenario
Equation	Equation 9

Data/Parameter	$CO_{2,FF,A,t}$
Unit	$t\,CO_2$
Data source	Estimated with equation 10
Description/ Comments	Carbon dioxide emissions due to fossil fuels in the project area A in year t
Equation	Equation 10, Equation 12

Data/Parameter	$EFF_{i,A,t}$
Unit	$t\,CO_2eq$
Data source	Estimated with Equation 11
Description/ Comments	Carbon dioxide emissions from fossil fuel combustion from type of fossil fuel i in project area A in year t
Equation	Equation 10, Equation 11

Data/Parameter	$CFF_{i,t}$
Unit	$liter$
Data source	Estimated on basis of documentation provided by the farmer

Description/ Comments	Fossil fuel consumption of type i in year t
Equation	Equation 11

Data/Parameter	$EF_{CO_2,i}$
Unit	factor
Data source	Peer reviewed scientific paper, suitable values can be selected from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 10 Table 10.10 and Table 10.11
Description/ Comments	Emission factor of fossil fuel type i
Equation	Equation 11

Data/Parameter	$CH_{4,ef,i,t}$
Unit	$t\ CH_4$
Data source	estimated with equation 13
Description/ Comments	Methane emission from livestock enteric fermentation ef in sample unit i in year t
Equation	Equation 13, Equation 14

Data/Parameter	$EF_{ent,l}$
Unit	$(kg\ CH_4/(head\ \times year)$
Data source	Peer reviewed scientific papers e.g. suitable values can be selected from the 2019 Refinement to

	the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 10 Table 10.10 and Table 10.11
Description/ Comments	Enteric emission factor for livestock type l
Equation	Equation 13

Data/Parameter	$P_{l,i,t}$
Unit	$head$
Data source	Documentation provided by the farmer
Description/ Comments	Total number of grazing livestock of type l in sample unit i in year t
Equation	Equation 13, Equation 15, Equation 19

Data/Parameter	$D_{l,i,t}$
Unit	$days$
Data source	Provided by the farmer
Description/ Comments	Grazing days per head in the years t for each livestock type l in sample unit i
Equation	Equation 13, Equation 15

Data/Parameter	GWP_{CH_4}
Unit	dimensionless

Data source	peer reviewed scientific papers e.g. suitable values can be selected from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Description/ Comments	Global warming potential for methane
Equation	Equation 14, Equation 16

Data/Parameter	$CO_2eq_{CH_4ef,A,t}$
Unit	$t\,CO_2$
Data source	Estimated withequation 14
Description/ Comments	Reduction of methane emissions from enteric fermentation in project area A in year t
Equation	Equation 14, Equation 17

Data/Parameter	$CH_{4,md,i,t}$
Unit	$t\,CH_4$
Data source	Estimated with equation 15
Description/ Comments	Total amount of methane emissions due to manure deposition in year t in sample unit i
Equation	Equation 15, Equation 16

Data/Parameter	$VS_{l,i,t}$

Unit	$\text{kg volatile solids}/(\text{head} * \text{day})$
Data source	Calculated on basis of documentation provided by the farmer and on default values retrieved from peer reviewed scientific papers e.g. suitable values can be selected from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Description/ Comments	Volatile solids per head per livestock type l in sample unit i in year t
Equation	Equation 15

Data/Parameter	$EF_{CH_4,md,l}$
Unit	$g\ CH_4/(kg\ volatile\ solids)$
Data source	Calculated on basis of documentation provided by the farmer and on default values retrieved from peer reviewed scientific papers e.g. suitable values can be selected from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Description/ Comments	Emission factor for methane emissions from manure deposition for livestock type l
Equation	Equation 15

Data/Parameter	$D_{l,i,t}$
Unit	$days$
Data source	Estimated on basis of data provided by the farmer
Description/ Comments	Average grazing days per head in for each livestock type l in sample unit i in year t
Equation	Equation 15

Data/Parameter	$CO_2eq_{CH_4md,A,t}$
Unit	$t\,CO_2eq$
Data source	Estimated with equation 16
Description/ Comments	Reduction of methane emissions from manure deposition in project area A in year t
Equation	Equation 16, Equation 17

Data/Parameter	$\Delta CO_2eq_{CH_4A,t}$
Unit	$t\,CO_2eq$
Data source	Estimated with equation 17
Description/ Comments	Reduction of methane emissions from manure deposition converted to CO_2 equivalents in the project area A in year t
Equation	Equation 17

Data/Parameter	$N_2O_{md,direct,i,t}$
Unit	$t\,N_2O/unit\,area$
Data source	Estimated with equation 18
Description/ Comments	Direct nitrous oxide emissions through manure deposition in sample unit i in year t
Equation	Equation 18, Equation 23

Data/Parameter	$EF_{N_2O,md,l}$
Unit	$\frac{kg\ N2O - N}{kg\ N}$
Data source	2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 11 Table 11.1
Description/ Comments	Emission factor for nitrous oxide from manure and urine deposited on soils by livestock type l
Equation	Equation 18

Data/Parameter	$N_{manure,l,i,t}$
Unit	$t\ N$
Data source	Estimated with equation 19
Description/ Comments	Amount of nitrogen in manure and urine deposited on soils by livestock type l in sample unit i in year t
Equation	Equation 19, Equation 21, Equation 22

Data/Parameter	Nex_l
Unit	$kg\ N/head/year$
Data source	Peer reviewed scientific papers e.g. suitable values can be selected from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 10 Table 10.19
Description/ Comments	Average annual nitrogen excretion per head of livestock type l
Equation	Equation 19

Data/Parameter	$F_{l,i,t}$
Unit	%
Data source	Calculated on the basis of livestock type and total presence in the sample unit
Description/ Comments	Fraction of total annual nitrogen excretion for each livestock type l for sample unit i in year t that is deposited on the project area
Equation	Equation 19

Data/Parameter	$N_2O_{md,indirect,i,t}$
Unit	$t\ N_2O$
Data source	Estimated with equation 19
Description/ Comments	Indirect nitrous oxide emissions due to manure deposition insample unit i in year t
Equation	Equation 20, Equation 23

Data/Parameter	$N_2O_{md,vol,i,t}$
Unit	$t\ N_2O/unit\ area$
Data source	Estimated with equation 21
Description/ Comments	Indirect nitrous oxide emissions produce from atmospheric deposition of N volatilized due to manure deposition for sample unit i in year t
Equation	Equation 21

Data/Parameter	$N_2O_{md,leach,i,t}$
Unit	$t\ N_2O/unit\ area$
Data source	Estimated with equation 22 or equal to 0 where annual precipitation is less than potential evapotranspiration, unless irrigation is employed
Description/ Comments	Indirect nitrous oxide emissions from leaching and runoff of, in regions where leaching and runoff occurs, as a result of manure deposition for sample unit i in year t.
Equation	Equation 22

Data/Parameter	$Frac_{GASM}$
Unit	dimensionless
Data source	2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 11 Table 11.3
Description/ Comments	Fraction of all organic N added to soils, N in manure and urine deposited on soils that volatilizes as NH_3 and NO_x
Equation	Equation 21

Data/Parameter	$EF_{N,vol}$
Unit	$tN_2O - N/(t\ NH_3 - N + NO_x\ - N\ volatilized)$
Data source	2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 11 Table 11.3
Description/ Comments	Emission factor for nitrous oxide emissions from atmospheric deposition of N on soils and water surfaces
Equation	Equation 21

Data/Parameter	$Frac_{LEACH}$
Unit	dimensionless
Data source	2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 11 Table 11.3 For humid climate zones, a factor of 15 is applied. In regions with dry climates where irrigation is used, a factor of 0,24 is applied. For dry climate zones, a value of 0 is applied.
Description/ Comments	Fraction of all organic N applied 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
Equation	Equation 22

Data/Parameter	$EF_{N,leach}$
Unit	$t\ N_2O - N/tN\ leached\ and\ runoff$
Data source	2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 11 Table 11.3
Description/ Comments	Emission factor for nitrous oxide emissions from leaching and runoff
Equation	Equation 22

Data/Parameter	$\Delta N_2O_{md,A,t}$
Unit	$t\ N_2O$
Data source	Estimated with equation 23
Description/ Comments	N_2O emissions due to manure deposition in project area A in year t
Equation	Equation 23

Data/Parameter	GWP_{N_2O}
Unit	dimensionless
Data source	peer reviewed scientific papers e.g. suitable values can be selected from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Description/ Comments	Global warming potential for nitrous oxide
Equation	Equation 24, Equation 28

Data/Parameter	$CO_2eq_{N_2O,md,A,t}$
Unit	$t\,CO_2$
Data source	Estimated with equation 23
Description/ Comments	Reduction in nitrous oxide emissions from manure deposition in project are A in year t
Equation	Equation 24, Equation 32

Data/Parameter	$\Delta N_2O_{F,A,t}$
Unit	$t\,CO_2eq$
Data source	Estimated with equation 25
Description/ Comments	Direct N_2O emission as a result of nitrogen application in project area A in year t
Equation	Equation 25, Equation 28

Data/Parameter	$F_{SN,t}$
Unit	$t\ N\ in\ year\ t$
Data source	Calculated with Equation 25
Description/ Comments	Mass of synthetic fertilizer nitrogen applied adjusted for volatilization as $NH_3$and NH_x
Equation	Equation 25, Equation 26

Data/Parameter	$F_{ON,t}$
Unit	$t\ N\ in\ year\ t$
Data source	Calculated with equation 27
Description/ Comments	Mass of organic fertilizer nitrogen applied adjusted for volatilization as $NH_3$and NH_x
Equation	Equation 25, Equation 27

Data/Parameter	EF_1
Unit	dimensionless
Data source	Peer reviewed scientific papers e.g. suitable values can be selected from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 11.2.1.2 Table 11.1
Description/ Comments	Emission factor for direct nitrous oxide emissions from N additions from synthetic fertilizers, organic amendments and crop residues
Equation	Equation 25

Data/Parameter	MW_{N_2O}
Unit	$(t - N2O)/(t - N)$
Data source	2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
Description/ Comments	Ratio of molecular weights of N_2O and N (44/28)
Equation	Equation 25, Equation 29

Data/Parameter	$M_{SFi,t}$
Unit	tonnes in year t
Data source	Documentation provided by the farmer
Description/ Comments	Mass of synthetic fertilizer type i applied in year t
Equation	Equation 26

Data/Parameter	$M_{OF,j,t}$
Unit	tonnes in year t
Data source	Documentation provided by the farmer
Description/ Comments	Mass of organic fertilizer type j applied in year t
Equation	Equation 27

Data/Parameter	$NC_{SF,i}$

Unit	$t\, N / t\, fertilizer$
Data source	Documentation provided by the farmer
Description/ Comments	Nitrogen content of synthetic fertilizer type i
Equation	Equation 26

Data/Parameter	$NC_{OF,j}$
Unit	$t\, N / t\, fertilizer$
Data source	Documentation provided by the farmer
Description/ Comments	Nitrogen content of organic fertilizer type j
Equation	Equation 27

Data/Parameter	$Frac_{GASF}$
Unit	dimensionless
Data source	Peer reviewed scientific papers e.g. suitable values can be selected from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 11.2.2.3 Table 11.3
Description/ Comments	Fraction that volatilises as NH_3 and NO_x from synthetic fertilizer
Equation	Equation 26

Data/Parameter	$Frac_{GASM}$

Unit	dimensionless
Data source	Peer reviewed scientific papers e.g. suitable values can be selected from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 11.2.2.3 Table 11.3
Description/ Comments	Fraction that volatilises as $NH_3$and $NO_x$from organic fertilizer
Equation	Equation 27

Data/Parameter	$CO_2eq_{N_2O,F,A,t}$
Unit	$t\ CO_2eq$
Data source	Estimated with equation 28
Description/ Comments	Reductions of nitrous oxide emissions from fertilizer use in project area A in year t
Equation	Equation 28, Equation 32

Data/Parameter	$\Delta N_2O_{Nfix,A,t}$
Unit	$t\ CO_2eq$
Data source	Estimated with Equation22
Description/ Comments	Amount of nitrous oxide emissions due to the use of N-fixing species in project area A in year t
Equation	Equation 29, Equation 31

Data/Parameter	$NFS_{t,A}$

Unit	$tonnes$
Data source	Equation 29
Description/ Comments	Amount of N-fixing species (above and below ground) returned to soils in the year t project area A.
Equation	Equation 29, Equation 30

Data/Parameter	EF_2
Unit	dimensionless
Data source	Peer reviewed scientific paper, suitable values can be selected from the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4
Description/ Comments	Emission factor for nitrous oxide emissions from N-fixing species
Equation	Equation 29

Data/Parameter	$DM_{g,i,t}$
Unit	$tonnes\ of dm$
Data source	Data provided by the farmer
Description/ Comments	Annual dry matter (above and below ground), N-fixing species g returned to soils for sample unit i in year t
Equation	Equation 30

Data/Parameter	$N_{cont,g}$

Unit	$t\, N/t\, dm$
Data source	2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 11 Table 11.2
Description/ Comments	Fraction of N in dry matter for N-fixing species g
Equation	Equation 30

Data/Parameter	$CO_2eq_{N_2o,Nfix,A,t}$
Unit	CO_2eq
Data source	Estimated with equation 31
Description/ Comments	Nitrous oxide emission reduction from nitrification/denitrification in year t in the project area A in year t
Equation	Equation 31, Equation 32

Data/Parameter	$\Delta CO_2eq_{N_2O,A,t}$
Unit	CO_2eq
Data source	Estimated with equation 32
Description/ Comments	Total amount of nitrous oxide emission reductions converted into CO_2eq in project area A in year t
Equation	Equation 32

Data/Parameter	$buffer$
Unit	CO_2eq

Data source	Respective Credit Class Document
Description/ Comments	Pool of certificates, serving as a security for project permanence
Equation	Equation 33, Equation 34

Data/Parameter	$IC_{reductions}$
Unit	$t\ CO_2eq$
Data source	Calculated with equation 33
Description/ Comments	Issuable CO2eq reduction credits for a specific project
Equation	Equation 33

Data/Parameter	$IC_{removals}$
Unit	$t\ CO_2eq$
Data source	Calculated with equation 34
Description/ Comments	Issuable CO2eq removal credits for a specific project
Equation	Equation 34

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