VCS Methodology

VM0032

Methodology for the Adoption of Sustainable Grasslands through Adjustment of Fire and Grazing

Version 1.0

16 July 2015

Sectoral Scope 14

Methodology developed by:

Soils for the Future

In partnership with:

The Nature Conservancy

Fauna and Flora International

TABLE OF CONTENTS

1 SOURCES

The following have informed the development of the methodology:

- The R Project for Statistical Computing
- IPCC, 2000. *Emissions: energy and transport*. Pages 55-70 Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. IPCC National Greenhouse Gas Inventories Programme
- IPCC, 2006. *Emissions from livestock and dung management*. Pages 1-85 Guidelines for National Greenhouse Gas Inventories. IPCC
- IPCC, 2006. *Grasslands*. Pages 1-49 Guidelines for Greenhouse Gas Inventories. IPCC
- IPCC, 2006. *Quantifying uncertainties in practice*. Chapter 6.*in* R. Odingo, editor. IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories IPCC
- Microsoft, 2006. *Monte Carlo Simulation for Excel*

This methodology uses the latest versions of the following tools:

- CDM A/R methodological tool *Calculation of the number of sample plots for measurements within A/R CDM project activities*
- VMD0016 *Methods for stratification of the project area (X-STR)*
- VT0001 *Tool for the Demonstration and Assessment of Additionality in VCS AFOLU Project Activities*
- VMD0040 *Leakage from Displacement of Grazing Activities*
- VCS *AFOLU Non-Permanence Risk Tool*

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

Additionality and Crediting Method	
Additionality	Project Method
Crediting Baseline	Project Method

2.1 Project Activities

The project activities eligible to apply this methodology include any that manipulate number and type of domestic livestock grazing animals (e,g cattle, sheep, horses, goats, camels, llamas, alpacas, guanacos, or buffalo) and/or grouping, timing and season of grazing (eg, continuous unrestricted, planned rotational, bunched herd rotational or other means of restricting livestock access to forage in order to allow vegetation response) in ways that sequester soil carbon and/or reduce methane emissions. Altering fire frequency and/or intensity, (eg, shifting from late season to early season burning or changing prescribed burn schedules from one every other year to one every five years) in ways that increase carbon inputs to soil, is also an included activity. Increased fire may be used to shift plant species composition such that net carbon sequestration in soil increases (eg, conducting a single burn to shift vegetation from shrubs to grasses), but the net increase in SOC must compensate for any losses in woody biomass and increases in methane (CH_4) and nitrous oxide (N_2O) emissions. Grassland restoration activities to improve livestock forage density (eg seeding of legumes or perennial grasses) that do not involve mechanical tillage of soil are allowed.

It is expected that such project activities will occur on grasslands that have historically experienced SOC loss. As these areas would continue to maintain low levels or further loss of SOC in the absence of the project, it is therefore expected that other carbon pools, such as aboveground carbon pools or biomass, will have relatively little change. The loss of SOC in the baseline prior to the project start date may be caused by fires that occur frequently enough to reduce SOC, or overgrazing that is expected to continue in the absence of the project.

Some grasslands (eg, savannas and open woodlands) may feature significant aboveground woody plant biomass that exceeds five percent of the soil carbon pool. Some woody biomass, largely in the form of shrubs or small trees, can reduce grass density and soil carbon. Management fires to reduce this woody cover might therefore reduce carbon in the aboveground woody biomass pool but compensate by increasing grass production and total carbon sequestration in soil.[1] Such scenarios are allowable under this methodology.

2.2 Quantification Approach

Projects may rely on measured or modeled approaches (see Table 1 below):

<u>Measured approach:</u> Emission reductions are quantified following a period in which enhanced soil sequestration and/or reduced methane emissions can be demonstrated. Such projects have a reduced uncertainty compared to those following a modeled approach, but projects that include soil sequestration activities may claim and verify emission reductions only after increases in soil carbon can be detected (likely every five or more years, depending on the productivity of the site).

<u>Modeled approach:</u> Emission reductions are quantified using a validated model after demonstrating management activities, which are known to sequester carbon and/or reduce methane emissions, have been implemented. Reduced emissions from sequestration and reduced methane emissions associated with these activities are then estimated by models with acceptable precision which have been validated for the project and re-calibrated at regular intervals thereafter (5-10 years, depending on the productivity of the site).

Modeled approaches have higher uncertainty due to the uncertainty in the parameters used to calculate emissions and removals and the uncertainty in whether model calculations actually describe changes in sequestration and reduced emissions. Consequently, verified modeled emission reductions will likely be reduced due to uncertainty deductions. However, because activities may be demonstrated annually, emission reductions may be verified annually, if desired.

This modeling approach requires the use of soil carbon models that have been published in peer-reviewed journal articles. Models must have been validated with independent data. Data used to validate the model must have been published in a peer-reviewed journal article and independent from data used to build the model. Soil carbon models describe how the density of soil organic carbon (SOC) changes as a result of biogeochemical processes and soil characteristics (eg, soil texture and type, pH, temperature, and moisture) and modifications in the capture of CO_2 and production of carbon-containing root and shoot biomass by plants. This aboveground and belowground biomass may undergo one of several fates:

1) Conversion back to CO_2 by combustion during fire,
2) Consumption and respiration by grazing animals,
3) Decomposition and respiration by microbes in soil and/or in the guts of invertebrate decomposers, or
4) Remaining as SOC from decomposed plant material or grazing animal dung.

As would be expected for such a complicated process, such models usually require the input of many parameters that need to be measured or obtained from the literature. When choosing which approach to take, the project proponent must consider carefully its ability to obtain necessary parameter measurements and to validate the chosen model for their project area.

Table 1: Summary of Measured vs Modeled Approaches

Measured Approach	Frequency	Modeled Approach	Frequency
Baseline			
Demonstration of SOC impoverishing activities		**Demonstration of SOC impoverishing activities**	
Measurements		**Measurements**	
* Initial SOC		* Initial SOC	
* Past grazing animal numbers		* Past grazing animal numbers	
* Forage quality		* Forage quality	
* Uncertainty analysis		* Past fire frequency	
		Build Model	
		* Choose model	
		* Measure/find parameters	
		* Accuracy assessment of prediction	
		* Predict initial SOC	
		* Monte Carlo analysis for uncertainty	
Project Scenario			
* Conduct activities	Every 5-10 years	* Conduct activities	Every 1-2 years
* Measure ΔSOC		* Measure/find parameters	
* Animal numbers during crediting period		* Measure project fire frequency	
* Forage quality during crediting period		* Measure grazing animal numbers	
* Uncertainty analysis		* Calculate methane emissions	
		* Uncertainty analysis	
Verified Carbon Unit Calculation at Verification			
* Methane	Every 5-10 years	* Calculate ΔSOC from model	Every 1-2 years
* Uncertainty analysis and deduction		* Methane	
***Claim VCU’s**		* Uncertainty analysis	
		*** Claim VCU's**	
Model Re-calibration			
		* Measure/find parameters	Every 5-10 years
		* Measure ΔSOC	
		* Assessment of prediction	
		* Model adjustment	

Table 1 summarizes the procedures for applying either the measured approach or the modeled approach. While there are additional steps to using the modeled approach compared to the measured approach, the project proponent may monitor activities and calculate emission reductions more frequently (eg every 1-2 years as opposed to every 5-10 years) with the measured approach.

2.3 Baseline and Project Emissions and Reductions

The project proponent must demonstrate baseline conditions for the 10 years prior to the project start date, including:

1) land uses,

2) fire histories such as the number of times, sections or strata of the project area burned and when these fires occurred, and

3) grazing livestock animal numbers from detailed records such as surveys of livestock owners, past aerial surveys or ground censuses of livestock animals. These data are necessary to assess baseline methane emissions from enteric fermentation.

Baseline conditions may be determined from analysis of past satellite images, such as MODIS Burned Area Product maps to assess fire histories or with other satellite imagery such as Landsat, with demonstrated suitability from peer-reviewed scientific papers and/or from data from the project area to detect vegetation types and trends. Interpretation of satellite images during the project crediting period coupled with ground assessments of the occurrence of fire at multiple sampling stations is needed for verification of fire-abatement activities.

For the project scenario, both the modeled and measured approaches require sampling of soils and measurement of bulk density and SOC. If using the modeled approach, the soil sample depth is determined by the model (eg, 20 – 100 cm). This sampling will occur at the start of the project and be used to establish the baseline scenario. Likewise, for both approaches, ground censuses, household surveys, and/or aerial surveys of grazing animal numbers broken out by species, sex, and age are needed to determine baseline methane emissions and project reductions (or increases).

The measured approach simply calculates the difference in SOC at each verification event since the project start date or previous verification event. Note that sufficient time must pass between verification events to detect changes in SOC (eg, five or more years, depending on productivity in the project area). The initial and subsequent measurements of SOC occur at each of many permanent sampling stations located in different subareas (strata) within the project area that differ strongly in current or past vegetation, soil types or management activities. The sum of the differences in SOC, called ΔSOC, at each sampling station across the project area reflects net GHG emission reductions and removals from the soil carbon pool.

If a modeled approach is used, measurements of parameters, or information used to obtain parameter values, must be available to be input into a peer-reviewed, published, and accuracy-tested (at least once) model of soil carbon dynamics (eg, SNAP[2] CENTURY[3, 4]], EPIC[4], or the Hurley Pasture[5] models). The model must include parameters impacted by project activities (eg, grazing intensity and fire frequency) as well as critical factors affecting carbon inputs and outputs to soil (eg, soil texture, climate, and plant characteristics that affect decomposition). The specific factors needed will depend on the model used, as some models, such as CENTURY, require more than 20 factors, while others, like SNAP, require only five factors. To ensure that a model predicts changes in emissions or removals accurately and precisely enough to achieve a sufficiently low uncertainty in estimated changes in carbon stocks from project activities, the chosen model must be tested to demonstrate it is appropriate for use in the project area. Such a test uses site condition and management history data to predict carbon stocks that reflect the consequence of past management actions and conditions, such as rainfall, plant species composition, grazing intensity and fire history. This predicted carbon stock is compared to current, measured carbon stocks and the accuracy and precision of the predictions must be demonstrated within subareas (strata) of the project area that differ strongly in past conditions or in management activities. The details of the model test are presented in section 8.1.3.3.

Following the model test, soil carbon dynamics are modeled for the project area to estimate the maximum SOC that would likely have occurred for the 10 years prior to the project start date, as the baseline SOC. The same model is then used to calculate an expected future equilibrium SOC under proposed project activities, the time in years to reach this equilibrium, and the average annual increment in SOC sequestration expected under the proposed project activities. The statistics of variation needed to calculate uncertainties for each parameter in the model are also required in order to determine an overall uncertainty in the model calculations of SOC through a Monte Carlo simulation analysis. Uncertainty in the difference between maximum SOC in the past 10 years and an expected future equilibrium SOC will be used to determine any potential uncertainty deduction (section 8.4.4).

2.4 Leakage

Emissions from leakage primarily occur from the displacement of current activities inside the project area to areas outside the project area. For this proposed methodology, leakage would occur primarily by displacement of livestock to other grazing lands in which grazing would result in loss of soil carbon and/or increased methane emissions. Such displacement is limited by the applicability conditions for the methodology, but where displacement does occur leakage emissions must be quantified according to the procedures within the methodology.

3 DEFINITIONS

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

3.1 Defined Terms

Baseline Period
A historical reference period over which the project's baseline emissions are calculated, and that consists of the ten consecutive years occurring immediately before the project start date

Calibration
Process by which predictive models use local measurements to determine the values of their parameters, and which will make the models more representative of the project area.

Calibration Period
Under a modeled approach, the time in years following the project start date or most recent re-calibration when soil carbon is to be measured again in order to re-calibrate the chosen soil carbon model. This period may be much longer than the verification period for modeled approach projects in order to allow sufficient time for measureable changes in soil carbon to occur

Cellulose
Carbon-rich plant material that, to decompose requires special enzymes (cellulases) typically found only in certain fungi, bacteria or other microorganisms

Enteric Fermentation
Process of microbial digestion of plant material in the digestive tract of grazing animals that, in the absence of oxygen, yields methane (CH_4) as a byproduct

Equilibrium
State of a carbon pool when inputs to the pool are balanced by outputs, such as when inputs to soil organic matter are balanced by losses from respiration by microorganisms

Exclosure
Fence or other device that excludes grazing animals from an area, sufficient to allow measurement of aboveground biomass inside in order to compare with biomass outside; used in estimating grazing intensity

Fire management
Set of practices that either inhibit fire or burn vegetation on purpose to achieve desired goals for vegetation and soil carbon.

Grasslands
Lands with more than 250 mm mean annual precipitation covered by natural and managed herbaceous cover that lack trees over 5m in height with greater than 50% canopy cover (forests)[1]

Grazing animal
Mammals that eat primarily herbaceous plants or the leaves of shrubs; in this methodology, applies to livestock species subject to control by the project proponent

Legumes
Plants in the pea family, either woody or non-woody, that harbor bacteria in their roots that perform nitrogen fixation, or the conversion of nitrogen gas in the atmosphere into chemical forms that can be used by plants

Lignin
Carbon-rich plant material that is generally impervious to decomposition by microorganisms

Neutral Detergent Fiber
Plant material resistant to rapid digestion or decomposition, which includes cellulose and lignin

[1] http://www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/gcwg/definitions/en/

Overgrazing
Grazing that has resulted in permanent vegetation species changes from mostly palatable to unpalatable species, reduction in vegetation cover that expose more than 80 percent bare ground, and/or consumption of more than 75 percent of production

Prescribed Fires
Fires that are set on purpose by landholders as part of a specific strategy to manage vegetation in the project area

Rotational Grazing
Various practices of planned grazing in which animals are restricted, by herding or fencing, to small portions (< 25%) of available grazing lands for relatively short periods of time, followed by movement to new portions of available grazing land. The restricted access and time is designed for livestock grazing animals to eventually visit all or most of available grazing lands but still allow forage plant species sufficient time and resources (water, nutrients) to regrow and set seed following grazing or to complete growth and seed set before grazing.

Soil Organic Carbon Density
Amount of carbon in the soil, expressed as a mass per unit area rather than as a percent

Soil Carbon Dynamic Model
A model published in the peer-reviewed scientific literature that predicts changes in soil organic carbon as a function of various input variables, which may include aboveground production, belowground production, precipitation, temperature, initial soil organic carbon, soil texture, and grazing intensity and possibly other factors detailed in the peer-reviewed article(s) describing the model

Soil Organic Carbon (SOC)
See VCS document *Program Definitions*.

Tier 1, 2, or 3
The level of precision and use of local measurements in calculating various emissions and removals of greenhouse gases, as assigned by the IPCC

3.2 Acronyms

A/R	Afforestation / Reforestation
AFOLU	Agriculture, Forestry and Other Land Use
AIC	Akaike Information Criterion
ALM	Agricultural Land Management
CDM	Clean Development Mechanism
CI	Confidence Interval

IPCC	Intergovernmental Panel on Climate Change
NDVI	Normalized Difference Vegetation Index
SAVI	Soil-Adjusted Vegetation Index
SGMAFG	Sustainable grassland management though adjustment of fire and grazing
UNFCCC	United Nations Framework Convention on Climate Change
VCS	Verified Carbon Standard
VCU	Verified Carbon Unit

4 APPLICABILITY CONDITIONS

This methodology applies to project activities that adjust the number, type and husbandry of grazing animals, adjust the frequency and intensity of planned or unplanned fires, and/or introduce herbaceous grassland species as potential forage for grazing animals or to restore degraded soils.

The methodology is applicable under the following conditions:

1) The project area must be grasslands in the baseline and project scenarios.
2) Lands are grazed and/or subject to fires in the baseline and/or project scenarios. Lands may be used for different purposes, such as livestock production, conservation, hunting or tourism.
3) The project must be structured to keep livestock within the project area, and the project proponent must be able to enforce the boundaries of the project area.
4) The project must result in no net increase in the density of, or time spent by animals in confined corrals where dung can pile up and begin to decompose anaerobically[5] and result in CH_4 and N_2O emissions, such as an increase in the number of livestock aggregated (eg, kept in corrals or pens) that would result in more than 50 percent of the ground area covered by dung.[2]
5) Baseline emissions derived from livelihood-driven human impacts on aboveground woody biomass (eg, cutting for fuel wood, charcoal or timber sales) must be deemed de minimis (ie, not included in the cumulative 95 percent of total baseline emissions) and project activities cannot significantly alter such livelihood-driven activities.
6) For projects that propose to modify grazing, the maximum individual project size[3] is 3 million ha or 5 percent of a country's land area currently or potentially used to graze livestock, as judged by national government land use inventories or other documentation.

[2] This criterion is conservative relative to the conditions of dung accumulation that would result in significant anaerobic decomposition

[3] These constraints are designed to avoid market leakage, such as if a reduction in livestock created a meat or milk shortage that would encourage overstocking of livestock elsewhere in a country

The methodology is not applicable under the following conditions:

- Project activities that involve mechanical vegetation removal or soil tillage
- The project area receives a net import of inorganic or organically-derived fertilizer

5 PROJECT BOUNDARY

The spatial extent of the project boundary must be established following the guidelines in the latest version of the VCS document *AFOLU Requirements*.

Table and 3 below identify the carbon pools and GHG sources included or excluded from the project boundary.

Table 2: Selected Carbon Pools under Baseline and Project Activity

Carbon Pools	Included?	Justification/ Explanation
Aboveground woody biomass	Optional	Where the project activities involve changes in fire management, the project proponent must monitor changes in aboveground woody plant biomass. Where the project activity is to reduce fire frequency, there may be increases in removals from woody biomass which must be quantified and monitored. Where the project plans to burn woody biomass to promote soil sequestration, aboveground woody biomass must be included, because woody plants in some savanna grasslands can account for 10-30 percent of carbon stocks[6] and can be dramatically reduced by fire. Where the project activities do not involve changes in fire management, quantification and monitoring of changes in removals from woody plant biomass is optional.
Aboveground non-woody biomass	No	Aboveground non-woody biomass is typically burned or decomposed within the same year of its production and therefore is not a major sink and is considered in balance with CO_2 uptake, respiration by plants, and annual decomposition[7]
Belowground biomass	No	Belowground non-woody biomass is typically burned or decomposed within the same year of its production and therefore is not considered a major sink in grasslands because it is considered in balance with CO_2 uptake, respiration by plants, and annual decomposition [7]. As tillage is not allowed according to applicability conditions, any increase from project activities may be conservatively excluded.
Dead wood	No	Negligible in grasslands, particularly those with fire.
Litter	No	In grasslands, litter exhibits high turnover which further reflects balance with CO_2 uptake, respiration by plants, and annual decomposition[7].
Soil organic carbon (SOC)	Yes	Major carbon pool covered by SGMAFG
Wood products	No	An optional pool for VCS ALM projects, it is considered negligible for untilled grasslands

This methodology has applicability conditions for no tillage and activities that do not include avoided conversion of grasslands. Consequently, aboveground non-woody biomass, litter, and belowground biomass are considered negligible sinks because they turnover considerably throughout the year, sometimes by as much as 100 percent [7]. These carbon pools may later be used as potential parameters for soil carbon models because they influence the input of carbon to the soil, but they do not represent significant, permanent sinks or reservoirs of carbon.

Table 3: GHG Sources Included In or Excluded From the Project Boundary

Source		Gas	Included?	Justification/Explanation
Baseline	Grazing animals	CO_2	No	Balanced with CO_2 uptake, respiration by plants, and annual decomposition [7]
		CH_4	Yes	Target removal for methodology
		N_2O	No	No increase in concentration of dung and forage if not fertilized (see applicability conditions)
	Burning biomass	CO_2	No	Balanced with CO_2 uptake by plants
		CH_4	Optional	If reducing or maintaining fire is a project activity, CH_4 may be conservatively excluded. Otherwise CH_4 emissions must be calculated to determine net change in carbon stocks from increasing fire to induce an increase in SOC
		N_2O	No	Negligible under applicability conditions
	Soil emissions	CO_2	No	Assumed to be in balance with C inputs to SOC (SOC at equilibrium)
		CH_4	No	Negligible since project is not in wetland
		N_2O	No	Negligible under applicability conditions
Project	Grazing animals	CO_2	No	Balanced with CO_2 uptake by plants
		CH_4	Yes	Target removal for methodology
		N_2O	No	No increase in concentration of dung (applicability conditions) and forage is low in N
	Burning biomass	CO_2	No	Balanced with CO_2 uptake by plants[7]
		CH_4	Optional	If reducing or maintaining fire is a project activity, may be conservatively excluded. Otherwise CH_4 emissions must be calculated to determine net change in carbon stocks from increasing fire to induce an increase in SOC
		N_2O	No	Negligible under applicability conditions
	Soil emissions	CO_2	No	Accounted for in measured ΔSOC
		CH_4	No	Negligible since project not in wetland
		N_2O	No	Negligible under applicability conditions

Unless specifically planted at high density to achieve aboveground biomass greater than 120 g/m^2 on average, leguminous plants, either woody (eg, *Acacia* or *Prosopis* species) or herbaceous, are not likely to produce soil N_2O emissions to levels that approach 5 percent of total CO_2 emissions from soil [8, 9]. Consequently, N_2O emissions from soil or biomass burning are negligible.

As per applicability condition 4, this methodology does not apply to projects that result in a net increase in the density of, or time spent by, animals in confined corrals where dung can pile up and begin to decompose anaerobically[5] and result in CH_4 and N_2O emissions. Dung in pastures or open rangelands typically decompose aerobically [10, 11], which releases negligible CH_4 and N_2O emissions.

Increase in the use of fossil fuels due to management, harvesting, and fighting fires is likely to be negligible because the same general activities (eg, livestock grazing, wildlife conservation and tourism) will be occurring in the project area during the project lifetime as under baseline conditions.

6 BASELINE SCENARIO

The baseline scenario is identified as the existing or historical land management practices, under the assumption that these would continue in the absence of the project. The baseline land management activities, such as plans (or lack thereof) for fire management, number of grazing animals and the duration and timing of grazing particular areas of land, must have been in place during the baseline period. In the case that management activities have changed during the baseline period, such changes must be documented and the activities leading to the lowest net emissions or greatest removals during the baseline period must be chosen as the most plausible baseline scenario.

To develop the baseline scenario, the project proponent must document, using published or gathered project-specific data and/or models, historic grazing plans or use of grazing areas by livestock and fire histories in the project area. The method to determine the most plausible baseline condition is provided in Section 8 (Baseline Emissions) with additional information provided in Section 9.3 (Description of the Monitoring Plan). The method includes:

1) Where adjustments in fire frequency and/or intensity are a project activity, the project proponent must demonstrate a fire history, as a map of areas that burned and the number of times they burned over the previous ten years. This may be obtained by using satellite products, such as MODIS Burned Area Product[4] as detailed in Section 9.3.5) that provide polygons of burned areas for 15 day periods throughout the dry or burning season. A GIS program like Quantum GIS (2.6)[5], and other programs like IDRISI [6] or ArcGIS, may perform similar functions. Project proponents may also use dated aerial

[4] http://modis.gsfc.nasa.gov/)
[5] Quantum GIS 2.4 can be downloaded for free at https://www.qgis.org
[6] http://www.clarklabs.org

photographs or accurate hand-drawn maps accompanied by records of where and when land parcels burned.

2) As evidence of past grazing practices and impacts, the project proponent must demonstrate a grazing history, as determined from past livestock grazing animal counts, ground measurements of grazing impacts, and/or ground-validated interpretations of satellite imagery (such as the Normalized Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI), or other similar index[12, 13]) from a minimum of four intervals across the 10 years, with at least one image from 8-10 years prior to the project start date.

3) Baseline methane emissions require as detailed as possible livestock grazing animal censuses through any combination of professional aerial surveys, ground counts with appropriate spatial extrapolation to the project area[14, 15], or household surveys of livestock held by each household over the previous 10 years. Censuses must categorize, to the extent possible, the species, sex, and age of each animal, and an average body weight for each category[7].

4) Aboveground woody biomass must be sampled at the project start from many locations in the project area (see Section 8.1.3.5) and if necessary for inclusion as a parameter in soil carbon models, analyzed for neutral detergent fiber, cellulose, and lignin in a professional laboratory.

5) Initial soil carbon stocks must be measured to the desired depth following Section 8.1.3.3. The chosen depth must match that applicable to the chosen soil carbon model if the modeled approach is used.

6) Where the modeled approach is used, predictions of soil carbon stocks or stock changes from the chosen model of soil carbon dynamics, such as Century[3, 4, 16], must be tested to demonstrate it is appropriate for use in the project area with measured soil carbon stocks or stock changes from the project area. Correlations between predicted and observed stocks must have $R^2 \geq 0.80$ within strata and an uncertainty based on a 95 percent confidence interval of ≤ 20 percent for predicted values applicable to the project area. The use of less accurate model predictions imply larger confidence limits in estimated carbon stocks or stock change after 10 years and thus larger uncertainty deductions in claimed emission reductions. If a model cannot be found to provide sufficient accuracy, the measured approach must be used.

7) The selected model is used to model the soil carbon dynamics and to estimate the maximum SOC that would have occurred in the 10 years prior to the project start date. This provides an uncertainty deduction for activity-based emission reduction calculations.

---

[5] IPCC, *Emissions from livestock and dung management*, in *Guidelines for Nartional Greenhouse Gas Inventories*. 2006, IPCC. p. 1-85.

[7] Such data are necessary to use Tier II methods of calculating methane emissions per IPCC 2006 guidelines

8) Where the measured approach is used, estimates of initial soil carbon stocks within different strata must also calculate an uncertainty based on a 95 percent confidence interval, with uncertainty deductions imposed if uncertainty exceeds ± 15 percent.

9) Uncertainty propagated by all estimated emissions and reductions must be calculated for baseline emissions, project emissions and reductions. Uncertainty deductions will occur if the total uncertainty ± 15% percent of estimated net emissions and removals under the project scenario. The deducted removals must be directly proportional to the uncertainty.

7 ADDITIONALITY

Additionality must be demonstrated using the latest version of the VCS tool VT0001 *Tool for the Demonstration and Assessment of Additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities*. In this tool, the project proponent must (1) identify alternative land use scenarios to the proposed project activity, (2) perform an investment analysis to determine that the proposed project activity is not the most economically or financially attractive of the identified land use scenarios or (3) identify key barriers, and (4) demonstrate how the proposed project activity deviates from common practice.

8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

8.1 Baseline Emissions

8.1.1 Baseline Management Activities

The project proponent must document the management activities that occurred during the baseline period, in order to quantify baseline emissions and/or removals. Management activities must include:

1) The number of livestock grazing animals of different categories (eg, weight, sex, age and species) in one or more areas within or in the entire project area.

2) The average forage removal, or grazing intensity (%) by all animals, as measured by comparison of forage biomass inside and outside fenced exclosures[2, 17], or inside and outside unfenced areas otherwise avoided by livestock, such as conservation areas, with similar soil and climate, or before and after planned grazing events. Estimates of grazing intensity over large areas may be made by using satellite-based indices, such as NDVI[12, 13] , as long as such indices are correlated with ground measurements with a $R^2 > 0.35$.

3) The pattern of time and timing of animal use of the project area.

4) Prescribed burns at some desired frequency.

Management activities may also be considered to mean a lack of management in the form of unplanned livestock grazing, lack of grazing, or unplanned fires. The project proponent must also provide evidence of the baseline vegetation conditions and their association with management activities in the project area during the baseline period. Such evidence must take the form of any one or combination of the following, in no particular order of preference:

5) Field data on vegetation composition (biomass, percent cover, incidence). Dominant vegetation types that are associated with lower soil carbon (eg, annual plants) or with grasses with high lignin and cellulose content such as various *Pennisetum* spp. (in Africa), *Spinifex* spp., (Australia), switchgrass *Panicum virgatum* or Johnson grass *Sorghum halepense* (North America), or *Paspalum* spp. (South America)) following consumption by livestock. These data may be presented as visually estimated percent cover of different vegetation types and average percent cover of annual and perennial grasses, bare ground and shrubs, must be provided if applicable.

6) Measurements of grazing intensity from exclosure (fence) experiments, visual estimates calibrated from exclosure experiments or ungrazed areas within the project area with similar soils and rainfall to areas where soil carbon is expected to be increased.

7) GPS-referenced, dated photographs of a representative sample of the project area, with sufficient evidence to judge a shift to project scenario vegetation from similar photographs taken of the same view at the same GPS point.

8) Interpreted satellite images, such as indices of NDVI[12, 13] or maps of burned areas[18, 19] across multiple years, coupled with ground vegetation data to support the conclusion that these images are correctly interpreted with reasonable accuracy (ie, R^2 > 0.35 between index and vegetation measure from 1).

8.1.2 Design and Establishment of Permanent Sampling Stations

This methodology depends greatly on the success at measuring changes in SOC, the results of project activities, and/or key inputs into soil carbon models such as grazing intensity and/or the intensity and frequency of fires. Because these measurements in grasslands often vary by a large amount over distances of a few meters, the project proponent must establish permanent sampling stations, marked with permanent materials, like PVC, metal or stone, with recorded GPS locations to 10 meter accuracy, or close enough to find the permanent markers of the station. Measurements of carbon stocks in soil and wood (if relevant) at the same place may then be compared over time and control for initial differences in SOC, grazing and fire history, vegetation, topography, and other factors. Project impacts on carbon stocks are therefore best detected by measuring the change in carbon stocks between years at each sampling station and then summed over all sampling stations rather than the difference between mean stocks across all sampling stations in different years. This sampling approach will greatly reduce the variance, and therefore, uncertainty, in changes in stocks between baseline and project activities. Further details about measurements at these permanent stations are discussed in Section 0.

8.1.2.1 Number of Sampling Stations

The total number of sampling stations, n, for the project area must be determined by using the CDM A/R methodological tool *Calculation of the number of sample plots for measurements within*

A/R CDM project activities.[20] As soil is typically sampled from three or more pooled 5-10 cm diameter cores at a station and therefore from a small total area (< 0.05 m^2), there are potentially a large number of potential sampling sites in even the smallest project area (< 1 km^2). Consequently, the total number of sampling stations, according to the CDM tool, is largely insensitive to the total area of the project for a measured approach as shown in see Figure .

Figure 1: Estimate Number of Sampling Stations

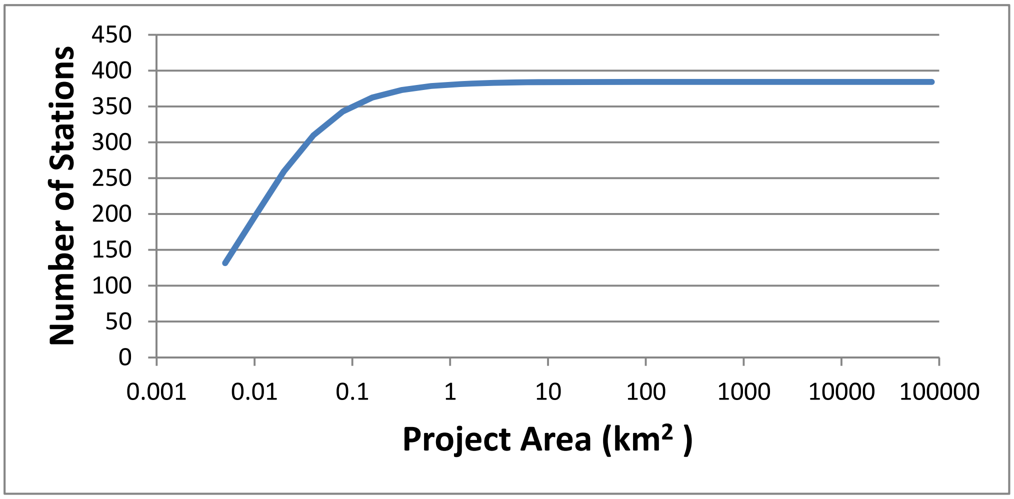


Figure 1 shows the estimated number of sampling stations needed to detect an increase in mean SOC of 0.3 percent for samples with a typically observed standard deviation of 0.3 percent (100 percent of mean) and target standard error of less than 10 percent.

8.1.2.2 Stratification

<u>Measured Approach</u>

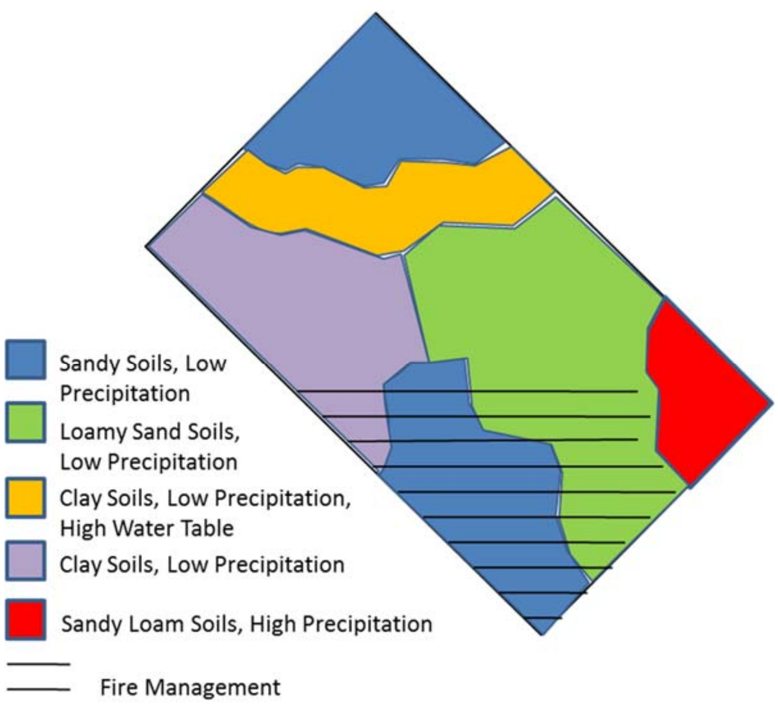
Obtaining precise estimates of soil organic carbon requires careful stratification[21, 22]. Stratification on the basis of vegetation and management practices must provide a good initial scope of stratification for soil, but additional factors, such as topography (top, middle and bottom of slopes), and texture (proportion of sand, silt and clay) may also be important for defining strata. A cluster, regression tree or other similar analysis of SOC from the permanent sampling stations, which is required to establish baseline SOC stocks, must be used to decide a final stratification. These types of analyses examine a set of different measurements from different locations to find groups of locations with similar values, and may be conducted in many ways depending on the extent of variability in soils, climate, and management in a project area[22]. For a detailed discussion and recommended approaches, see references [23, 24].

Rather than limit uncertainty in absolute measurement of SOC stocks, a modeled approach has the goal to reduce the 95 percent confidence interval of a regression line of predicted change in SOC relative to observed change in SOC. This imposes an additional emphasis for the distribution of sampling stations to include the largest possible variation in SOC, both in terms of the strata chosen and in sampling variation within strata.

Using cluster analysis, regression tree analysis or any other means, such as the latest version of the VCS module VMD0016 *Methods for stratification of the project area (X-STR), v1.0* [25], the project proponent must classify the area by past management practices and preliminary information about soils (such as from a soils map) and climatic conditions (such as from areas that are similar in aboveground productivity, or from rainfall maps). This step is equivalent to stratification in an afforestation / reforestation project[20] but focused on factors related to soil carbon sequestration[7], fire frequency, and animal distribution and management, and reduces the uncertainty in estimates of project removals of GHG. This will produce *s* strata within which baseline and project emissions are calculated, soil carbon changes and methane emissions will be monitored, and past (baseline) and proposed project management activities have been (are) implemented.

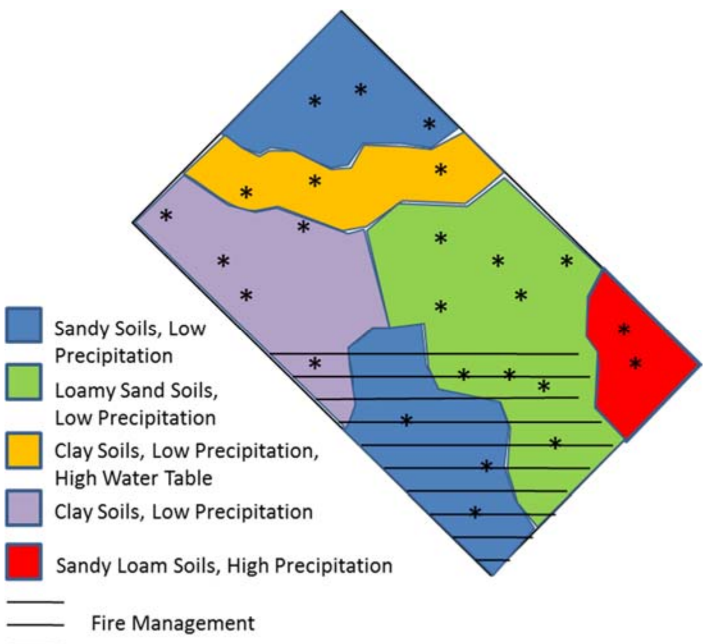
As an example, a project might be subdivided into five areas of different soil type and/or precipitation as seen in Figure . The sampling design would then feature eight strata, one for each combination of management activity, soil type, and precipitation or water availability.

Figure 2: Hypothetical Landscape among Eight Strata Subject to Different Management Practices



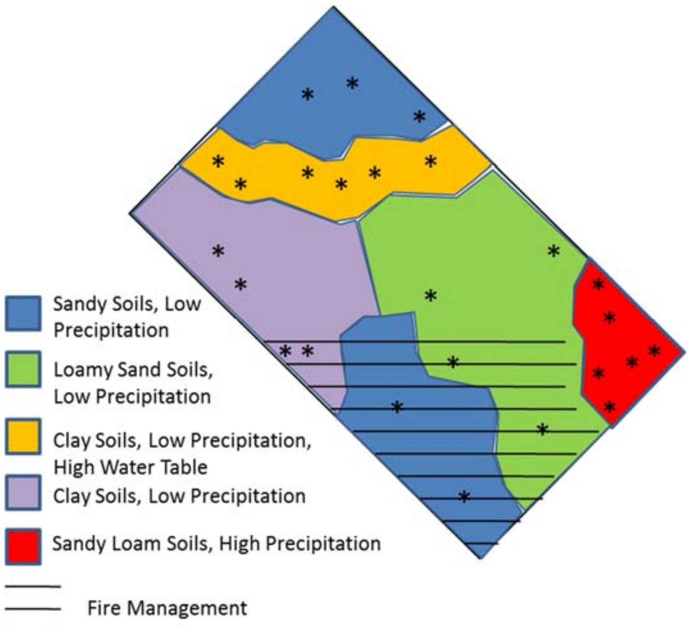
Once each stratum is defined and mapped and the total number of sampling stations determined, then a representative number of sample points, z_m, are chosen within each stratum. The number of points per stratum will depend on which stratified sampling method is used. Where SOC exhibits similar variability among strata (ie, coefficients of variation (standard deviation/mean) differ by less than 40% in areas with different soil, vegetation, or management practices), the number of stations per stratum must be proportional to the proportional area of each stratum in the project area. This is the most likely scenario under the expectation that strata for a project are selected to ensure a low variance (10 percent standard error) within each stratum. For example, in a project with three strata, A, B, and C that represent 50 percent, 40 percent and 10 percent respectively of the total project area and the project area requires 100 sampling stations, then 50, 40, and 10 stations must be placed randomly within each of strata A, B, and C as shown in **Error! Reference source not found.**3 below. This is the case of proportional allocation, which the number of stations is allocated to each stratum on the basis of its proportion of the total project area.

Figure 3: Proportional Allocation of Sampling Stations (Stars) Among the Eight Strata in the Hypothetical Project Area in Figure 2



Alternatively, the best possible stratification of the project area, resulting in the least uncertainty, may still feature certain strata that exhibit much higher variability (> 40% difference in coefficient of variation) in SOC than others. In this case, “optimum” or disproportionate allocation of stations may be most appropriate. Where a disproportionate application is applied, strata receive a number of sampling stations proportional to their coefficient of variation rather than their proportional area. In the example, hypothetical strata A, B, C might receive 20, 20, and 60 percent of stations, respectively if SOC in stratum C is three times more variable (three times higher coefficient of variation), regardless of their proportional areas. As an example, Figure 4 shows the disproportionate allocation of 25 sampling stations in the hypothetical project area shown below. In this case the high precipitation stratum and the clay soils with a high water table are three times more variable than other strata, and thus receive 6 stations, as opposed to two.

Figure 4: Optimal or Disproportional Allocation of Sampling Stations (Stars) Among the Eight Strata of the Hypothetical Project Area in Figure



The primary goal of the distribution of stations must be to reduce variability and increase representation of different SOC values in the project area.

Modeled Approach

For projects using a modeled approach, the objective is to demonstrate that the chosen soil carbon model can predict SOC stocks or changes in SOC stocks at each of a large number of sampling stations that differ in key factors, such as climate soil type, past management, and vegetation. Sampling stations must be selected to encompass as much of the variability in these factors as possible in order to test that the model is appropriate for use in the project area (see Section 8.1.3.3. The sample size must be determined using an online calculator[8] or a power analysis in any standard statistics program. As an example, to achieve the desired model accuracy of $R^2 > 0.80$ (see Section 8.1.3.3) and an uncertainty of less than 0.08, a total of 120 samples would be needed from across the full variation in SOC within the project area.

8.1.3 Calculation of Baseline Emissions

[8] One resource for online calculators is http://www.danielsoper.com/statcalc3

8.1.3.1 Baseline Emissions from Grazing Animals (BEM)

Baseline methane emissions from grazing animals must be estimated from data on total numbers for different livestock categories that reflect species, age, sex and their respective weights, in the project area. The methodology applies to Tier 2 approaches, as outlined in the *IPCC 2006 Guidelines for National Greenhouse Gas Inventories* Chapter 10, Emissions From Livestock and Dung Management[5] but with local input data. Calculations are based on estimating daily methane emissions as a function of the body weight (kg) of each major animal category [26] (Figure 5: Daily Methane Emissions Data), and then multiplied by the number of animals in each animal category and 365 days in a year. Emissions from all categories may then be summed to provide the total annual methane emissions for the project area. Domestic livestock grazing animals of category c must be classified as one of three animal types: ruminants (sheep, goats, cattle, buffalo, and camelids (ie, camels, alpacas, guanacos, llamas), equids (donkeys, horses) or pigs.

$$BEM = \sum_{c=1}^{K} \left(BN_C \times DMEF(W_c)\right) \times GWP_{CH_4} \times 365 \times 6.26x10^{-7} \quad (1)$$

Where:

BEM	= Baseline annual emissions from grazing animals (tCO_2e)
BN_c	= Baseline number of animals of category *c* (head)
$DMEF(W_c)$	= Daily emission factor as a function of animal weight for category *c* (L CH_4 / day)
$W_{C,}$	= Average body weight during the baseline period for animals of category *c* (kg)
GWP_{CH4}	= Global warming potential for methane (tCO_2e / tCH_4)
c	= category of grazing animals
K	= number of categories of grazing animals, eg species, gender, age combinations
365	= Conversion factor for days to years
6.26×10^{-7}	= Conversion factor for L CH_4 / day to t CH_4 / day

Further, $DMEF(W_c)$ is the daily emission factor (liters CH_4 / day) as a function of animal weight for animal category c. These values must be determined using the relevant allometric equations in **Error! Reference source not found.**.

Table 4: Allometric Equations, with Uncertainty, for Daily Methane Emissions for Three Animal Types: Ruminants, Equids, And Pigs

Animal Type	Equation	n	R^2	Uncertainty Percent
Ruminants	$0.66 \times W_C^{0.97}$	62	0.88	9.5%
Equids	$0.18 \times W_C^{0.97}$	23	0.76	28.2%
Pigs	$0.07 \times W_C^{0.99}$	12	0.93	18.6%

BN_c, is the harmonic mean number of animals of each category during the 10 years prior to the project start date, calculated as below. The harmonic mean conservatively weights lower values of methane emissions in a sample[27]. This must be calculated using equation (2). The harmonic mean BN_c for n censuses[27] of $N_{c,i}$ animals in each category c during census i is given by:

$$BN_c = \left(\frac{1}{n}\right) \times \left(\frac{1}{\sum_{i=1}^{n} \frac{1}{N_{c,i}}}\right) \qquad (2)$$

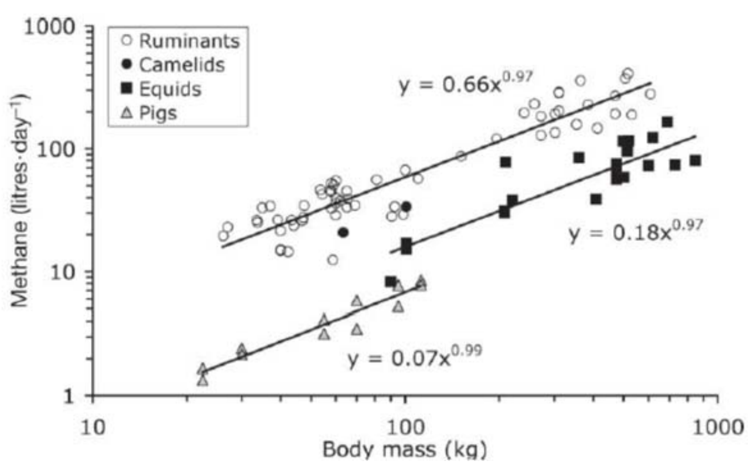
Where:

BN_c	= Baseline number of animals of category *c* (head)
n	= Number of counts
$N_{c,i}$	= Animals in category *c* during count *i* (head)

Calculations of uncertainty are given in Section 8.4.2.1.

Figure 5 shows the daily methane emissions data compiled from the Franz *et al.* (2010) review of 62 measurements for ruminants (sheep, goats, cattle and buffalo), 23 measurements for equids (donkeys and horses) and 12 measurements for pigs, showing how methane emissions scale with body weight W (kg). All animals were fed roughage forage similar in quality (40-50 percent neutral detergent fiber) to plants consumed in unfertilized grasslands that likely apply in this methodology. These relationships are summarized in **Error! Reference source not found.** above.

Figure 5: Daily Methane Emissions Data



Forage quality, and specifically the fiber content of forage, is known to affect methane emissions[28]. However, forage quality is not included because it introduces additional error into the calculation, since dry matter intake would also have to be estimated to yield methane emissions. Furthermore, the forage quality actually consumed, as opposed to that available, by free-living animals on grasslands can probably never be measured accurately across a large-scale project. So instead, it is expected that the uncertainties in the allometric equations in **Error!**

Reference source not found. are irreducible without impractical and prohibitively expensive direct methane measurements on individual animals[28] Depending on the relative abundance of equids in the composition of animals, this uncertainty in methane emissions may induce an uncertainty deduction in the calculation of removed methane emissions.

8.1.3.2 Baseline Emissions of Methane from Burning of Biomass (BEBB)

Biomass burning results in annual emissions of methane. These emissions may be conservatively excluded if project activities do not change or lead to decreased annual emissions, in which case BEBB = 0. If project activities decrease fire, proponents can choose to include biomass burning in baseline emission calculations and show the net decrease in such emissions under the project scenario. If project activities increase fire frequency, such as to remove shrubs and lead to a net increase in total carbon stocks from the increase in SOC associated with establishment of perennial grasses, project proponents must calculate the net change in emissions from biomass burning under the project scenario, BEBB, must be calculated with the following equation:

$$BEBB = \frac{\sum_{m}^{M}\left(FFREQ_{m,b} \times APB_{m,b} \times PA_{m,b}\right) \times BC_{G} \times EF_{BG} \times GWP_{CH_4}}{1{,}000{,}000} \quad (3)$$

Where,

BEBB	= Baseline annual emissions of methane from burning of biomass (tCO_2e)
$FFREQ_{m,}$	= Proportion of area of stratum *m* burned annually (percent)
$APB_{m,}$	= Mean total aboveground biomass at the end of the growing season in stratum *m* (kg biomass/ha)
$PA_{m,}$	= Baseline area in stratum *m* (ha)
BC_G	= Baseline combustion factor for savanna/grassland (kg biomass burned/kg biomass)
EF_{BG}	= Emission factor for the burning of grassland (g CH_4/kg biomass burned)
GWP_{CH4}	= Global warming potential of CH_4 (tCO_2e / tCH_4)
1,000,000	= Converts g CH_4 into Mg (tons)

8.1.3.3 Baseline Changes in SOC Density

The determination of a change in baseline equilibrium carbon density depends on the type of project approach used.

Measured Approach**.** Where the measured approach is applied, initial $SOC_{m,j,0}$ at each sampling station is the baseline. Initial $SOC_{m,j,0}$ may be calculated from multiple pooled soil cores from each station as:

$$SOC_{m,j,0} = DEPTH_{m,j,0} \times SOC\%_{m,j,0} \times BULK_{m,j,0} \quad (4)$$

Where:

$SOC_{m,j,0}$ = SOC density in station *j* in stratum *m* at time *t =0* (tC/ha)
$DEPTH_{m,j,0}$ = Depth of SOC sampling at the project start (cm)
$SOC\%_{m,j,0}$ = Percent SOC in dry soil from the entire soil profile to the chosen depth at station *j* in stratum *m* at time *t =0* (percent)
$BULK_{m,j,0}$ = Bulk density at station *j* in stratum *m* at time *t =0* (Mg dry soil / m^3) (Note Mg/m^3 are equivalent to g/cm^3, the unit most commonly reported by laboratory analyses)

Note that $SOC\%_{m,j,0}$ is a percent and allows the equation to correctly calculate SOC density (tons/ha).

$DEPTH_{m,j,0}$ must be selected by the project proponent to account for the vast majority (> 80 percent) of SOC in the soil column, reflect depth to hardpans or bedrock, or to match calculations from soil carbon models. $SOC\%_{m,j,0}$ and $BULK_{m,j,0}$ must be measured in a professional laboratory through either combustion methods[29] or multi-spectral diffraction with an infra-red spectrometer following project area-specific calibrations[30]. Bulk density accounts for whether soil is loosely or densely packed and must not include volume occupied by rock fragments or pebbles.

Modeled approach. Baseline management activities and environmental conditions driven by possible project activities, such as grazing intensity and fire frequency, as well as critical factors affecting carbon inputs and outputs to soil, such as soil texture, climate and plant characteristics that affect decomposition must be imported into a peer-reviewed, published soil carbon dynamics model that has been assessed for accuracy at least once with an independent set of data other than that used to construct the model. For example, SNAP[3] CENTURY[4, 16, 31], EPIC[32, 33], Hurley Pasture[34, 35] models are four models that incorporate grazing and/or fire, among others, as factors determining soil carbon.

One or more of these or other candidate models must be assessed for accuracy independently, (ie, with data other than that used to construct the model), and also tested to demonstrate it is appropriate for use in the project area by showing its ability to predict initial carbon stocks in different subareas (strata) within the project area (see below). This analysis assumes that past practices have been in place long enough for SOC to approach equilibrium. Thus the soil carbon model must be able to predict this equilibrium for strata in the project that have experienced similar management activities for 20 years or more. A regression line is fitted to a scatter-plot of model-predicted SOC (x-axis) vs. measured SOC from a large number permanent sampling stations[36] (see section 8.1.2.2). Variation in conditions and management activities across strata may be used as the source of different soil carbon model parameter inputs. The model must generate a coefficient of determination $R^2 > 0.80$ across all strata. The slope of the regression line must have a 95 percent confidence interval that overlaps 1 and the 95 percent confidence interval of the intercept must overlap zero. If these criteria cannot be met with any available models, then the project proponents must use the measured approach.

Bias must be determined by evaluating the percent bias of a simulation (carbon model) relative to observed data[37].

$$MBIAS = \frac{\sum_{i=1}^{n}(Y^{obs}{}_i - Y^{pred}{}_i)}{\sum_{i=1}^{n} Y^{obs}{}_i} \quad (5)$$

Where:

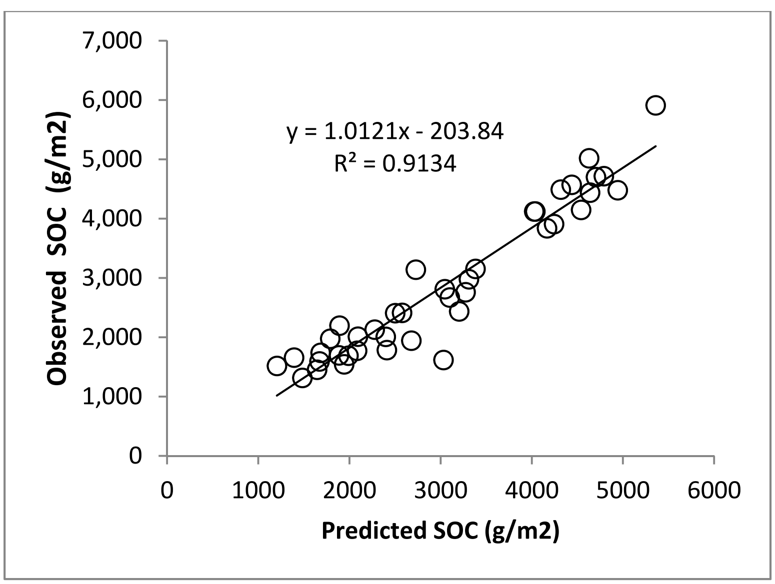
MBIAS	= Percent bias of carbon model predictions relative to observed data
n	= number of sampling stations tested
$Y^{obs}{}_i$	= observed SOC density at station i
$Y^{pred}{}_i$	= SOC density predicted at station i

Bias of the model chosen for this methodology must be between -20% and +20%.The criteria of $R^2 > 0.80$, slope = 1 and intercept = 0 should ensure that -20% $\leq$ MBIAS $\leq$ 20% [37]. In the case that significant bias is found and emission reductions are over-predicted— a subset of observed data may be used to adjust model parameters and fit the model to data, and then the model may be re-tested with the remaining data.

In addition the 95 percent confidence interval for predicted mean SOC, derived from Monte Carlo simulations, must overlap with that of SOC measured at sampling stations in the same stratum. If, for certain strata, the 95 percent confidence intervals do not overlap, then the soil carbon model must be calibrated for that stratum by adjusting one or more parameters until 95 percent confidence intervals do overlap.

Figure provides an example test of predicted SOC (g/m^2) of a soil carbon model with observed measured SOC, showing the regression line, coefficient of determination R^2 and the degree of variation around the regression line expected for an accurate, precise model for calculating baseline SOC and changes in SOC.

Figure 6: Example Test of Predicted SOC (G/M^2) of a Soil Carbon Model with Observed Measured SOC



The statistics of variation needed to calculate uncertainties for each parameter in the model are also necessary to determine an overall uncertainty in the model calculations of SOC. Total uncertainty of model predictions of baseline SOC, changes in SOC or eventual equilibrium SOC may be determined by an analysis called Monte Carlo simulation[3, 38]. In such a simulation, parameter values are randomly chosen from hypothetical normal distributions with mean equal to the parameter value and the measured standard error around that mean. Once all the different parameter values for the model are generated from the hypothetical distributions, a model prediction is made. This process is repeated 100 or more times to produce a mean model prediction with a 95 percent confidence interval. For baseline SOC, the Monte Carlo simulation would generate an expected value of SOC and a 95 percent confidence interval.

In some cases, alternative soil carbon models, and/or the same modeling framework with different sets of input parameters, may be appropriate for the same project area and activity[39]. If so, the project proponent must match predictions of different models to observed SOC and choose the model that best predicts current $SOC_{m,j,0}$ at each station in stratum m with the lowest Akaike Information Criterion (AIC) value, as per standard model selection procedures[40] Different models may use different numbers of parameters, so AIC is a statistic that measures the amount of variation in observation that is not predicted by a model, corrected for the number of parameters K used in the model to make the prediction:

$$AIC = n \times ln\left(\frac{\sum_{i=1}^{n} e_i^2}{n}\right) + 2K + 2K\left(\frac{K+1}{n-K-1}\right) \quad (6)$$

Where:

AIC	= Akaike Information Criterion value
n	= Number of observations tested, and
e_i	= Deviation of an observation from its model prediction
K	= Number of parameters used

Note that models, such as CENTURY[4, 16, 31], with large numbers of parameters (> 80) require a large number of observations n > K to even generate AIC, and such models would have to generate vastly greater fits (higher R^2, lower $\sum_{i=1}^{n} e_i^2$) to observations than much simpler models with fewer parameters, such as the Hurley Pasture model[2, 34, 35].

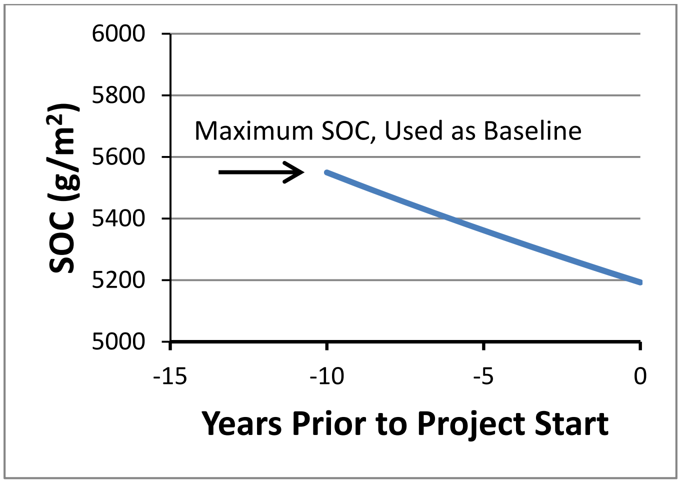
The chosen model must be re-calibrated as soon as changes in SOC may be measured (typically 5 or more years but up to a maximum of 10 years) since the project start date or most recent re-calibration (calibration period). In this case, the model should be used to detect the change in soil carbon during the previous calibration period rather than to predict carbon stocks. Necessary model parameters must be measured as discussed previously in this section and predictions of change in soil carbon stocks must be compared against measured changes at each of the permanent sampling sites using the regression approaches outlined previously in this section. Again, the model should predict observed change in soil carbon with $R^2 > 0.80$ and RMSR < 0.7. If the selected model fails to successfully predict soil carbon changes according to these criteria, then the project proponent may modify the model, or re-calibrate it. Re-calibration may occur by adjusting parameter inputs or coefficients in the model's functions in a reasonable way (justified by peer-reviewed scientific literature) to achieve successful prediction of changes in SOC during the calibration period.

8.1.3.4 Generating Baseline SOC with a Soil Carbon Model

Projects applying a modeled approach, must apply the maximum SOC in the previous 10 years as the baseline SOC stocks. For most projects, this will not have been measured, so the soil carbon model of choice must be used to "back cast," that is estimate SOC that would have occurred during the baseline period**.**

Figure **7**7 provides an example of back casting SOC change from current SOC, based on knowledge of past management activities and environmental conditions. The blue line is predicted SOC of previous years (x-axis). This example shows what baseline SOC would be 10 years prior (5549 g/m^2 at year 10) rather than current (5192 g/m^2 at year 1), thus increasing conservatism in the estimate of baseline SOC.

Figure 7: Example of Back-Casting SOC Change from Current SOC



Maximum baseline $MSOC_{m,j,0}$ for each station in each stratum must be estimated by back casting the chosen model (Figure 7: Example of Back-Casting SOC Change from Current SOC) with model input parameters associated with the soil type, plant species, climate and management activity of that stratum.

Overall, the soil carbon model may be used to estimate a modeled baseline SOC density, $MSOC_{m,j,0}$ = maximum SOC density (tons/ha) at sampling station *j* in stratum *m* during the baseline period.

$$MSOC_{m,j,0} = max(MSOC_{m,j,b}) \quad (7)$$

Where:

$MSOC_{m,j,0}$ = Modeled SOC in station *j* in stratum *m* at *time t =0* (tC / ha)

$MSOC_{m,j,b}$	= Modeled SOC in station *j* in stratum *m* for year *b* during the baseline period (tC / ha)

8.1.3.5 Baseline Emission Removals from Existing Woody Perennials (BRWP)

Under the applicability condition that baseline emissions derived from livelihood-driven human impacts on aboveground woody biomass must be negligible and project activities cannot significantly alter such livelihood-driven activities, it is likely that fire and grazing are the main drivers of change in aboveground woody vegetation. Where a reduction in fire frequency is a project activity, woody plant carbon stocks will increase as a consequence, and reversals of past and ongoing losses of woody plant biomass may be conservatively excluded (ie, BRWP = 0).

If past grazing pressure has been high enough to reduce fuel loads, past fire frequency may have been very low and woody plants, particularly shrubs, may have become abundant. If so, activities to sequester carbon may entail an increase in fire frequency that will reduce aboveground woody biomass but lead to an increase in soil carbon sequestration sufficient to increase total carbon stocks[1]. If fire is employed to change vegetation, aboveground woody biomass, must be accounted for in calculating project emissions and removals.

8.2 Project Emissions

Project emissions and removals depend on the principal set of project activities. Projects that reduce fire events need to account only for changes in methane emissions by grazing animals and changes in SOC. Projects that increase fire events to remove unpalatable woody plants—usually shrubs—in order to stimulate grass and root production can increase total carbon stocks. These projects must account for increased methane emission from biomass burning and emissions from decreased aboveground woody biomass carbon.

8.2.1 Project Methane Emissions from Grazing Animals (PEM_t)

If project activities will include reduction in livestock numbers, then accompanying removals from reduced methane emissions must be conservatively excluded from project removals. This avoids potential leakage from shifting of animals to adjacent grasslands or from market leakage whereby other producers increase livestock numbers to replace project livestock reductions and meet market demand. However, whether or not methane emissions from livestock are reduced, calculations must be based on project data from animal counts or censuses and emission factor data based on project area-applicable body weight of each category from the equations in **Error! Reference source not found.** and Equation (1) (Section 8.1.3.1).

$$PEM_t = \sum_{c=1}^{K} \left(PN_{C,t} \times DMEf\left(W_{C,t}\right)\right) \times GWP_{CH_4} \times 365 \times 6.26x10^{-7} \quad (8)$$

Where:

PEM_t	= Project emissions of CH_4 from grazing animals at year t (tCO_2e)

$PN_{C,t}$	= Number of animals of each category *c* in year *t* (head)
$DMEf(W_{C,t})$	= Daily emission factor as a function of animal weight for category *c* (L CH_4 / day)
$W_{C,t}$	= Average body weight during year t for animals of category *c* (kg)
GWP_{CH4}	= Global warming potential for methane (tCO_2e / tCH_4)
365	= Conversion factor for days to years
6.26×10^{-7}	= Conversion factor for L CH_4 / day to tCH_4 / day

The parameters are similar to those used for calculating baseline methane emissions. The number of grazing animal must be measured, because new animal categories may result due to project activities (eg, there is a shift to using different breeds or species of livestock).

8.2.2 Project Emissions from Burning of Biomass ($PEBB_t$)

Where project activities reduce the frequency of fire, this emission may be conservatively excluded, in which case $PEBB_t = 0$. Where project activities increase fire frequency (eg, to remove shrubs) and lead to a net increase in total carbon stocks, the baseline emissions of methane due to burning of biomass, $PEBB_t$, t CO_2e, are calculated using the following equation:

$$PEBB_t = \frac{\sum_m^s \left(PFFREQ_{m,t} \times {\left(\sum_{j=1}^{z_m} APB_{j,m,t}\right)} \big/ {z_m} \right) \times PA_{m,t} \times PC_G \times EF_{BG} \times GWP_{CH_4}}{1{,}000{,}000} \quad (9)$$

Where:

$PEBB_t$	= Project emissions of CH_4 due to biomass burning in stratum m in year t (tCO_2e)
$PFFREQ_{m,t}$	= Proportion of area of stratum *m* burned in year t (percent)
$APB_{j,m,t}$	= Aboveground plant biomass at sampling station *j* in stratum *m* in year *t* at the beginning of the dry/cold/ or burning season (kg biomass/ha)
z_m	= Number of sampling stations in stratum *m* at time *t*
$PA_{m,t}$	= Project area in stratum *m* at time *t* (ha)
PC_G	= Project combustion factor for savanna/grassland (kg biomass burned / kg biomass
EF_{BG}	= Emission factor for the burning of grassland (g CH_4 / kg biomass burned)
GWP_{CH4}	= Global warming potential of CH_4 (t CO_2e / t CH_4)
1,000,000	= factor for converting g CH_4 into tons

The project combustion factor ($PC_{G)}$ may be estimated in two ways. The project proponent may apply the most applicable IPCC default value [9] or may measure the mean proportion of aboveground biomass after fire ($APB_{m,j,f}$) at the sampling stations in the project area that burned compared with the pre-fire aboveground biomass ($APB_{m,j,t}$) at each station *j* within each stratum *m*[42] :

[9] Table 2.6 in 41. IPCC, *Guidelines for National Greenhouse Gas Inventories* 2006. **4**(Chapter 2).

$$PC_G = 1 - \frac{\sum_{j=1}^{F}\left(\frac{APB_{j,m,f}}{APB_{j,m,t}}\right)}{F} \tag{10}$$

Where:

PC_G	= Project combustion factor for savanna/grassland (kg biomass burned/kg biomass
$APB_{j,m,f}$	= Aboveground plant biomass in stratum *m* in year *t* immediately following fire (kg biomass /ha)
$APB_{j,m,t}$	= Aboveground plant biomass at station *j* in stratum *m* in year *t* at the beginning of the dry/cold or burning season (kg biomass/ha)
F	= Number of sampling stations that burned

8.2.3 Project Changes in SOC Density

The determination of change from baseline equilibrium SOC density depends on the type of project approach used.

Measured Approach:

Where the measured approach is applied, the project sequestration of SOC (in t CO_2e/ha) is calculated using the following equation:

$$PRS_t = {}^{44}/_{12} \times \sum_{m=1}^{s} \frac{PA_m}{z_m} \times \sum_{j=1}^{z_m} \frac{SOC_{m,j,t} - SOC_{m,j,v}}{Y} \tag{11}$$

Where:

PRS_t	= Project removals due to changes in SOC stocks in year *t* (tCO_2e)
PA_m	= Project area of stratum *m* (ha)
s	= Number of strata in the project area
z_m	= Number of sampling stations in stratum *m*
$SOC_{m,j,,v}$	= Baseline SOC in station *j* in stratum *m* in year v, If this is the first monitoring period, v= 0, for subsequent monitoring periods, v represents the year of last verification (tC)
$SOC_{m,j,t}$	= Project SOC measured at station *j* in stratum *m* in year *t* (tC/ha)
Y	= Length of the monitoring period (years)
44/12	= Conversion factor from tC to tCO_2e

$$SOC_{m,j,t} = DEPTH_{m,j,t} \times SOC\%_{m,j,t} \times BULK_{m,j,t} \tag{12}$$

Where:

$SOC_{m,j,t}$	= Project SOC measured at station *j* in stratum *m* in year *t* (tC/ha)

$DEPTH_{m,j,t}$ = Soil core depth (cm)

$SOC\%_{m,j,t}$ = Percent soil carbon at time *t* (percent)

$BULK_{m,j,t}$ = Bulk density at station *j* in stratum *m* in year *t* (Mg dry soil/m^3; or equivalently, g dry soil/cm^3)

Note that this formula assumes that SOC in year *Y* and in year *0* (baseline or since last verification) will be measured at a large number (100-1000) of sampling stations *j* in a stratified project area, including z_m stations in each stratum *m* (see Section 0).

Modeled Approach:

The selected project area-validated soil carbon model (see Section 8.1.3.3) must be used to simulate a projected equilibrium SOC density, called the project modeled SOC, $PSOC^{eq}_{m,j}$ for sampling station in each stratum under expected project activities. Expected grazing intensities and/or fire frequencies under project activities will combine in the model with other parameters as needed for the chosen soil carbon model to generate $PSOC^{eq}_{m,j}$ for each sampling station The input parameters for the soil carbon model must be chosen to such that conservative estimates of carbon removals are generated. Uncertainties for each parameter in the model must be available to determine an overall uncertainty for $PSOC^{eq}_{m,j}$ with a Monte Carlo simulation[3, 43, 44], as discussed in detail in Section 8.1.3.3. The model must also calculate the number of years *D* to reach this equilibrium.

Carbon typically accrues in response to management changes with decreasing increments over time as equilibrium is approached[4, 33, 35]. Thus conservatively, the annual increment in SOC is determined by the difference in SOC between the conservative baseline maximum from 10 years prior to the project start ($MSOC_{m,j,0}$) and project modeled equilibrium ($PSOC^{eq}_{m,j,t}$) divided by the time necessary to achieve project equilibrium (D). The project equilibrium must be determined assuming that project activities will be implemented. Thus, multiplying the annual increment in SOC (tons/ha), by the conversion of C to CO_2 44/12 yields CO_2e at that station.

$$PRS_{m,t} = {}^{44}/_{12} \times \frac{PSOC_m^{eq} - MSOC_{m,0}}{D} \tag{13}$$

Where:

$PRS_{m,t}$ = Annual project removals due to changes in SOC stocks in stratum *m* in year *t* (tCO_2e /ha)

$PSOC^{eq}_{m,}$ = Project modeled equilibrium SOC at station *j* in stratum *m* (tC/ha) based on parameter values from z_m sampling stations in stratum *m*

$MSOC_{m,0}$ = Modeled SOC for stratum *m* at time *t =0* (tC/ha) (see section 8.1.3.3)

D = Years required to achieve equilibrium

44/12 = Conversion factor from tC to tCO_2e

$$PRS_t = \sum_{m}^{s} (PA_{m,t} \times PRS_{m,t}) \quad (14)$$

Where:

PRS_t	= Project removals due to changes in SOC stocks in year t (tCO_2e)
$PA_{m,t}$	= Project area of stratum m in year t (ha)
s	= Number of strata in the project area
z_m	= Number of sampling stations in stratum m
$PRS_{m,j,t}$	= Annual project removals due to changes in SOC stocks at station j in stratum m in year t (tCO_2e / ha)

8.2.4 Project Emissions and Removals from Existing Woody Plants ($PERWP_t$)

Where project activities involve changes in fire management, the project proponent must monitor changes in aboveground woody plant biomass (AWPB) to quantify sequestration of GHG in aboveground woody plant carbon from reductions in fire or to ensure that losses of woody biomass from increased fire do not outweigh potential gains from soil carbon sequestration. Where the project activities do not involve changes in fire management, the project proponent may exclude the aboveground and belowground woody biomass pool by assuming PERWP = 0.

$$PERWP_t = \frac{{}^{44}/_{12} \times C \times \sum_{m=1}^{s} \frac{PA_{m,Y}}{z_m} \times \sum_{j=1}^{z_m} AWPB_{m,j,0} - AWPB_{m,j,Y}}{1000 \times Y} \quad (15)$$

Where:

$PERWP_t$	= Project emissions from changes in aboveground woody biomass in year t (tCO_2e)
44/12	= Conversion factor from C to CO_2e
C	= Proportion of wood composed of carbon[45, 46] (kg C/kg biomass)
$PA_{m,Y}$	= Project area of stratum m in year Y (ha)
z_m	= Number of sampling stations in stratum m
s	= Number of strata in the project area
$AWPB_{m,j,0}$	= Aboveground woody biomass at the project start date or beginning of the monitoring period at station j in stratum m; (kg biomass/ha)
$AWPB_{m,j,Y}$	= Aboveground woody biomass at station j in stratum m in year Y (kg biomass/ha)
Y	= Length of the monitoring period (years)
1000	= Conversion factor from kg to t

8.3 Leakage

8.3.1 Estimation of Leakage

This methodology considers two forms of leakage: displacement leakage from the movement of livestock off the project area where they may reduce soil carbon, and market leakage, where reductions in livestock numbers as a project activity would create market incentives to replace the lost livestock.

$$LE_t = LD_t + LM_t \tag{16}$$

Where:

LE_t = total leakage emissions in year t (tCO_2e)

LD_t = leakage emissions from displaced livestock in year t (tCO_2e)

LM_t = emissions from market leakage in year t (tCO_2e)

8.3.1.1 Leakage Emissions From Displaced Livestock

Increased GHG emissions from the displacement of livestock outside the project area is limited by the applicability condition that the project must be structured to keep livestock within the project area, and the project proponent must be able to enforce the boundaries of the project area. The project proponent must prevent incursion of livestock from outside the project area or excursion of livestock from inside the project area through fencing, patrolling by game scouts, or other such enforcement of project area boundaries.

The project proponent is expected to control grazing animal numbers inside the project area and account for the number of animals involved and duration of any movement of livestock to outside the project area. Mechanisms must be in place to prevent incursion of livestock onto project lands and to monitor and prevent migration or transport of livestock out of project lands. Such mechanisms may include fencing of private lands, governance structures that penalize lack of cooperation and participation, education, and monitoring on communal grazing lands. Nevertheless, monitoring of project activities may reveal that livestock excursions outside the project area have occurred and any impacts of such excursions on GHG emissions or reductions outside the project area must be accounted for as leakage. Where the project area is not fenced, such as in pastoralist systems, the movement and excursion of livestock to more than two kilometers from the project area boundary is considered leakage.[10]

Leakage methane emissions are deemed as zero because movement of project livestock off the project area does not result in a net increase in the number of livestock emitting methane. However, movement of livestock could result in losses of carbon from higher levels of overgrazing off the project area. Leakage may be accounted in two possible ways: monitored approach or penalty approach.

[10] This distance allows for possible uncertainty of herders as to the position of herds in or out of the project area and is a typical allowable buffer between ethnic group communal grazing lands [48]

A monitored approach allows livestock to graze on either planned (identified) or unplanned (unidentified) land parcels outside the project area, such land parcels must be classified as grassland, forest, or cropland. In this approach, potential vegetation impacts and baseline SOC in these outside areas must be measured/monitored, following VMD0040 *Leakage from Displacement of Grazing Activities*.

The penalty approach is a more conservative option (leakage calculations will likely be larger) but no monitoring of soils and/or vegetation outside the project area is required and off-project area use of grasslands, croplands, and forests is not differentiated. In this case, displacement leakage (LD_t) must be calculated as a proportion of net removals from increased soil carbon in year *t* (PRS_t), based on the proportion of total project livestock-days in project year *t*, 365 x $PN_{c,t}$, that occurred outside the project area.

$$LD_t = \frac{\sum_{x=1}^{d}\sum_{c=1}^{k} DN_{c,x}}{365 \times \sum_{c=1}^{k} PN_{c,t}} \times PRS_t \quad (17)$$

Where:

LD_t	= Leakage emissions from displaced livestock (tCO_2e)
$DN_{C,x}$	= Number of livestock of each category *c* that were off the project area on day *x* (head)
d	= Total number of days livestock were off the project area
k	= Total number of livestock categories
$PN_{C,t}$	= Number of animals of each category *c* in year *t* (head)
PRS_t	= Project removals due to changes in SOC stocks in year *t* (tCO_2e)

Alternatively, where using the monitored approach to calculating leakage, the methods for accounting for losses of SOC in VCS module VMD0040 (in Sections 5.2.4 through 5.2.6) must be followed for unidentified grasslands, croplands, and forests. Because this approach explicitly estimates actual losses of SOC from livestock grazing, it is more accurate in its calculation of leakage, and requires the measurement of many additional parameters, as defined in the module. The project proponent, for example, whose livestock were displaced only onto additional grasslands, would be required to measure a number of parameters including, the area of parcels affected, aboveground net primary production, and the number of livestock using the area prior to livestock displacement and following displacement. The monitored approach to calculating displacement leakage does not need to account for CH_4 or N_2O emissions. Methane emissions from project livestock will not change even if livestock are displaced off the project area, and the applicability conditions limit any net increase in dung deposition. Other impacts, such as deforestation or degradation associated with livestock use of forests, or removal of crop residues by livestock must be included in leakage calculations using the monitored approach, if they cannot be shown to be negligible (ie, greater than 0.05 x PER_t, equation 18)

8.3.1.2 Market Leakage Emissions

These result from an increase in activity by other producers of a commodity outside the project area to compensate for the reduced supply of a commodity from within the project area, such as increased timber harvesting elsewhere in a country to compensate for reduced harvesting in a project area). Market leakage is generally considered to be minimal in ALM projects[47] because the projects still allow the same livelihood choices and production of grassland commodities (eg, livestock). The applicability condition that limits project size, and thus potential impact of the project on national and international markets, reduces the chance that project activities will result in declining supply of livestock. Nevertheless, market leakage for any reductions in livestock must be made by using the VCS module VMD0033 “Estimation of emissions from market leakage”[11] to estimate LM_t emissions from market leakage.

Fire alterations are not expected to dramatically alter livelihood choices, (eg, would not prevent use of land for livestock, wildlife conservation, tourism). Projects that manage fire or otherwise do not reduce livestock need not account for market leakage.

Total leakage is negligible where:

$$LE_t < 0.05 \times PNR_t \tag{18}$$

Where:

LE_t	= Total leakage emissions (tCO_2e)
PNR_t	= Project emissions plus removals in year t (tCO_2e)

8.4 Net GHG Emission Reduction and Removals

The estimation of net project emission reductions, PER_t, and net change in carbon stocks, $NCCS_t$, each year of the monitoring period is calculated using the following equation:

$$PER_t = PEM_t + PEBB_t - BEM - BEBB \tag{19}$$

Where:

PER_t	= Net project emission reductions in year t (tCO_2e)
PEM_t	= Project methane emissions from livestock in year t (tCO_2e)
$PEBB_t$	= Project emissions from biomass burning in year t (tCO_2e)
BEM	= Baseline methane emissions from livestock (tCO_2e)
$BEBB$	= Baseline emissions from biomass burning (tCO_2e)

Note that if project methane emissions decrease relative to the baseline from removal of livestock from the project area (note, not from forage improvement), ie $PEM_t – BEM < 0$, this GHG removal must be conservatively excluded to avoid market leakage, and proponents must set $PEM_t – BEM = 0$.

[11] http://www.v-c-s.org/sites/v-c-s.org/files/VMD0033%20Estimation%20of%20Emission%20from%20Market%20Leakage%2C%20v1.0.pdf

$$NCCS_t = PRS_t \pm PERWP_t \qquad (20)$$

Where:

$NCCS_t$	= Net change in carbon stocks in year t (tCO_2e)
PRS_t	= Project removals due to sequestration of soil carbon in year t (tCO_2e)
$PERWP_t$	= Project removals due to loss or gain of carbon stocks in woody biomass in year t (tCO_2e)

The net GHG benefit is calculated using the following equation:

$$R_t = PER_t + NCCS_t - LE_t \qquad (21)$$

Where:

R_t	= Net GHG emission reductions and removals in year t (tCO_2e)
PER_t	= Net project emission reductions in year t (tCO_2e)
$NCCS_t$	= Net change in carbon stocks in year t (tCO_2e)
LE_t	= Total leakage changes in soil carbon in year t (tCO_2e)

8.4.1 Ex-Ante Calculations of Net Emissions and Removals

The project must perform an ex-ante (before project) calculation of expected or estimated net emissions and removals. The key to making such a calculation is to define project quantitative management objectives for fire frequency and/or grazing management compared to baseline activities. The project proponent must do the following:

1) Show a table of baseline and proposed project scenario management activities.
2) Show a table of expected parameters and emissions and removals, and their uncertainties, associated with those management objectives; use data from the peer-reviewed literature, measure activities in the project area, or calculate with a model the resulting changes in emissions and removals associated with the management.
3) Calculate expected project scenario emissions and removals, and their uncertainties, based on these management targets.
4) Show a table of baseline emissions, project emissions and removals, leakage (if any), and total net greenhouse gas emissions and removals for each year of the project crediting period.

8.4.2 Estimation of Uncertainty

The *VCS Standard*[49] requires that uncertainty be calculated on the basis of the full width of the 95 percent CI expressed as a percentage of the estimate of each emission or removal. IPCC Guidelines[43] recommend using a Tier 2 approach to determine uncertainty where emission reductions are determined by a combination of measurements, published emission factors, and process models, such as a soil carbon model. A Tier 2 approach involves conducting Monte Carlo simulations[3, 38], which must calculate R_t from equation (21) (see section 8.4) more than 100 times, with each calculation drawing randomly from hypothetical normal distributions of expected values of each parameter in the calculation, as defined by the mean and standard errors of each parameter. This simulation gives a mean and standard deviation of net emissions and removals R_t that are used to calculate uncertainty (equation (22)). Such Monte Carlo simulations may be done in online computing environments, such as the R Project for Statistical Computing[48], or even with macros developed for spreadsheets[44].

$$UNR_t = \frac{3.84 \times 100 \times SD(MCR_{t,n})}{MCR_t \times (n-1)^{1/2}} \tag{22}$$

Where:

UNR_t = total uncertainty in net emission reductions and removals, not including leakage (%)

n = number of Monte Carlo simulation runs performed (must be > 100)

MCR_t = mean net emissions reductions and removals at time *t*, from *n* Monte Carlo calculations of R_t, (tCO_2e)

$SD(MCR_{t,n})$ = standard deviation of R_t from *n* Monte Carlo simulations

Alternatively, total uncertainty may be calculated by weighting uncertainties according to the magnitude of emission or removal. In this case, uncertainty in net reductions and removals UNR_t is driven by uncertainty in baseline emissions, project emissions and project net changes in carbon stocks.

$$UNR_t = \frac{((\mathrm{UPE}_t \text{ x } (\mathrm{PEM}_t + \mathrm{PEBB}_t))^2 + (\mathrm{UNCCS}_t \text{ x } \mathrm{NCCS}_t)^2 + (\mathrm{UBE} \text{ x } (\mathrm{BEM} + BEBB))^2)^{1/2}}{PEM_t + PEBB_t + NCCS_t + BEM + BEBB} \tag{23}$$

Where:

UNR_t = uncertainty in net emission reductions and removals, not including leakage, at time *t* (%)

UPE_t = uncertainty in project emissions at time *t* (%)

$UNCCS_t$ = uncertainty in net change in carbon stocks at time *t* (%)

UBE = uncertainty in baseline emissions (%)

BEM = baseline animal methane emissions (tCO_2e)

PEM_t = project animal methane emissions at time *t* (tCO_2e)

BEBB = baseline emissions from biomass burning (tCO_2e)

$PEBB_t$ = project emissions from biomass burning (tCO_2e)

$NCCS_t$ = net project changes in carbon stocks (tCO_2e)

Each of the three component uncertainties are derived in detail below

8.4.2.1 Uncertainty in the Baseline

For the calculation of baseline emissions and reductions, BER, uncertainty arises in the calculation of methane emissions only, because all other net emissions are conservatively assumed to be zero, unless increasing fire frequency is a proposed management activity.

In this case:

$$UBE = UBEM \tag{24}$$

Where:

UBE = Uncertainty in baseline emissions (%)
UBEM = Uncertainty in baseline methane emissions from grazing animals (go to section 8.4.2.1.1) (%)

In the case of proposed activities to increase fire frequency:

$$UBE = \frac{((BEM \times UBEM)^2 + \sum_{m=1}^{s}(UBEBB_m \times BEBB_m)^2)^{1/2}}{BEM + \sum_{m=1}^{s} BEBB_m} \tag{25}$$

Where:

$UBEBB_m$ = Uncertainty in baseline methane emissions from burning of biomass (%)
BEM = baseline methane emissions from animals (tCO_2e)
BEBB = baseline emissions from burning of biomass (tCO_2e)

8.4.2.1.1 Uncertainty in baseline methane emissions from grazing animals (UBEM)

$$UBEM = \frac{(\sum_{c=1}^{k}(BEM_c \times UBEM_c)^2)^{\frac{1}{2}}}{\sum_{c=1}^{k} BEM_c} \tag{26}$$

Where:

UBEM = Uncertainty in baseline methane emissions from grazing animals (%)
$UBEM_c$ = Uncertainty in baseline methane emissions from animals in category *c* (%)
BEM_c = Baseline emissions from animals in category *c* (tCO_2e)

$UBEM_c$ is the uncertainty in methane emissions from animals in category c, as dictated by whether the animals are ruminants, equids, or pigs (see Section 8.1.3.1),. $UBEM_c$ is calculated from the uncertainty, for each animal category, in the regression equations predicting per animal daily methane emission (DME_c) based on the mean body weight ($UDME_c$, **Error! Reference source not found.**) and the uncertainty in the harmonic mean of animal counts (UBN_c) during the baseline period.

To obtain UBN_c , first find $SEBN_c$, the standard error[50] of the harmonic mean BN_c of the series' $N_{c,i}$ of animals in category *c* in count *i* of *n* counts or censuses.

$$SEBN_c = (BNc)^2 \times \frac{SD\left(\frac{1}{N_{c,i}}\right)}{(n-1)^{1/2}} \quad (27)$$

Where:

$SEBN_c$	= Standard error of the harmonic mean of animal counts in category *c*
$SD(1/N_{c,i})$	= Standard deviation of the inverses of the count *I* of animals in category *c*
$N_{c,i}$	= Animals in category *c* in census *i* (head)
BN_c	= Harmonic mean number of animals in category *c* (head) during the baseline period (head)
n	= Number of censuses

The 95 percent confidence interval-based uncertainty in the estimated number of animals in category *c* is:

$$UBN_c = 3.84 \times 100 \times \frac{SEBN_c}{BN_c} \quad (28)$$

Where:

UBN_c	= Uncertainty in the harmonic mean of animal counts (%)
$SEBN_c$	= Standard error of the harmonic mean of animal counts
BN_c	= Baseline number of animals of category *c* (head)
3.84	= Multiplier converts expression into a 95% confidence interval
100	= Multiplier converts expression into percent

$$UBEM_c = \left(UBN_c{}^2 + UDME_c{}^2\right)^{1/2} \quad (29)$$

Where:

$UBEM_c$	= Uncertainty in baseline methane emissions from animals in category *c* (%)
UBN_c	= Uncertainty in the baseline harmonic mean of animals of category *c* (%)
$UDME_c$	= Uncertainty in the regression for predicting daily methane emissions for animals of category *c* (%)

8.4.2.1.2 Baseline methane emissions from burning of biomass (BEBB)

In the case of project activities that increase fire frequency, uncertainty in BEBB (UBEBB) is driven by uncertainty in fire frequency ($UFFREQ_m$) in stratum *m* (or mean proportion of area burned), and uncertainty in mean within-stratum aboveground plant biomass at the end of the growing season, $UAPB_m$. $UFFREQ_m$ arises from either the 95 percent confidence interval in annual variation in proportion of area burned over a period of 10 or more years prior to the start date or from uncertainty in the interpretation of satellite images in burned area mapping in stratum *m* resulting from mis-identification or classification errors of burned versus unburned areas[19].

$$UFFREQ_m = 3.84 \times \frac{SD\left(FFREQ_{m,BY}\right)}{FFREQ_m \times (BY-1)^{1/2}} \times 100 \quad (30)$$

Where:

$UFFREQ_m$	= uncertainty (%) in fire frequency within stratum *m*
$SD(FFREQ_{m,t})$	= standard deviation in fire frequency in stratum *m* over *BY* years in the baseline period.
BY	= number of years in baseline period for which burned area is measured
$FFREQ_m$	= mean proportion of area burned during the baseline period
100	= converts the expression into percent
3.84	= converts the numerator into a 95% confidence interval

$UAPB_m$ arises from the 95 percent confidence interval among permanent sampling stations in clipped, dried, and weighed biomass.

$$UAPB_m = 3.84 \times 100 \times \frac{SD(APB_{z_m})}{APB_m \times (z_m - 1)^{1/2}} \quad (31)$$

Where:

$UAPB_m$	= uncertainty in aboveground plant biomass within stratum *m*
$SD(APB_{zm})$	= standard deviation in aboveground plant biomass among z_m permanent sampling stations in stratum *m*
z_m	= number of sampling stations in stratum *m*
APB_m	= mean aboveground plant biomass in stratum *m* (kg/m^2)

Therefore these two sources of uncertainty combine as

$$UBEBB = \frac{\left(\sum_m^s \left(BA_m \times \left(UFFREQ_m{}^2 + UAPB_m^2\right)^{1/2}\right)^2\right)^{1/2}}{PA} \quad (32)$$

Where:

UBEBB	= Uncertainty in baseline methane emissions from burning of biomass
$UFFREQ_m$	= Uncertainty in the fire frequency in stratum *m*
$UAPB_m$	= Uncertainty in mean within-stratum aboveground plant biomass at the end of the growing season in stratum *m*
BA_m	= Baseline area of stratum *m* (ha)
PA	= size of the project area (ha)
s	= number of strata

8.4.2.2 Uncertainty under the project scenario

Uncertainty under the project scenario using a weighted uncertainty approach is determined by uncertainty in project emissions or in carbon stocks, weighted by the magnitude of each, for each year of the monitoring period.

$$UPE_t = \frac{\left((PEM \times UPEM)^2 + \sum_{m=1}^{s}\left(PEBB_{m,t} \times UPEBB_{m,t}\right)^2\right)^{\frac{1}{2}}}{PEM + \sum_{m=1}^{s} PEBB_{m,t}}$$

(33)

Where:

UPE_t	= Uncertainty in project emissions (%)
$UPEM_t$	= Uncertainty in project methane emissions from grazing animals (%)
$UPEBB_{m,t}$	= Uncertainty in project methane emissions from burning of biomass (%)
PEM	= project methane emissions by animals during the monitoring period (tCO_2e)
$PEBB_{m,t}$	= project emissions from biomass burning in stratum *m* at time *t* (tCO_2e)

$$UNCCS_t = \frac{\left(\sum_{m=1}^{s}\left(PRS_{m,t} \times UPRS_{m,t}\right)^2 + \sum_{m=1}^{s}\left(PERWP_{m,t} \times UPERWP_{m,t}\right)^2\right)^{1/2}}{\sum_{m=1}^{s} PRS_{m,t} + \sum_{m=1}^{s} PERWP_{m,t}}$$

(34)

$UNCCS_t$	= Uncertainty in net changes in carbon stocks (%)
$UPRS_{m,t}$	= Uncertainty in project reductions from soil sequestration (%)
$UPERWP_{m,t}$	= Uncertainty in project emissions or removals from woody plants (%)
$PRS_{m,t}$	= Removals from changes in soil carbon stocks in stratum *m* at time *t* (tCO_2e)
$PERWP_{m,t}$	= Removals from changes in woody plant carbon stocks in stratum *m* at time *t* (tCO_2e)

8.4.2.2.1 Uncertainty in Project Methane Emissions

$$UPEM = \frac{\left(\sum_{c=1}^{k}(PEM_c \times UPEM_c)^2\right)^{1/2}}{\sum_{c=1}^{k} PEM_c}$$ (35)

Where:

$UPEM$	= Uncertainty in project methane emissions from grazing animals during the monitoring period (%)
$UPEM_{c,}$	= Uncertainty in project methane emissions from animals in category *c* (%)
PEM_c	= project methane emissions from animals in category *c* (tCO_2e)

$UPEM_{c,}$ is the uncertainty in methane emissions calculated from the uncertainty, for each animal category, in the regression equations for per animal daily methane production (**Error! Reference source not found.**) and the uncertainty in the arithmetic mean of animal censuses for category *c*, PN_c, during the monitoring period.

$$UPEM_{c,} = \left(UPN_c{}^2 + UDME_c{}^2\right)^{1/2}$$ (36)

Where:

UPN_c = Uncertainty in the project mean of animals of category *c*

$$UPN_c = 3.84 \times 100 \times \frac{SD(PN_{c,Y})}{PN_c \times (Y\text{-}1)^{1/2}} \quad (37)$$

Where:

$SD(PN_{c,Y})$ = Standard deviation of animal counts in category *c* across Y years of the monitoring period

PN_c = Arithmetic mean of animal numbers in category *c* (head)

Y = Years in the monitoring period

3.84 = Multiplier that converts the numerator into a 95% confidence interval

100 = Multiplier that converts the expression into percent

$UPME_c$ = Uncertainty in the regression, taken from the literature (Table 4) for predicting daily methane emissions for animals of category *c*

8.4.2.2.2 Uncertainty in Project Emissions From Burning Of Biomass

In the case of project activities that increase fire frequency, uncertainty in PEBB, or UPEBB, is driven by uncertainty in fire frequency ($UFFREQ_m$) in stratum *m* (or mean proportion of area burned), and uncertainty in mean within-stratum aboveground plant biomass at the end of the growing season, $UAPB_m$. $UFFREQ_m$ arises from either the 95 percent confidence interval in annual variation in proportion of area burned over the period since last validation or from uncertainty in the interpretation of satellite images in burned area mapping in stratum m resulting from misidentification or classification errors of burned versus unburned areas[19]. $UAPB_m$ arises from the 95 percent confidence interval among permanent sampling stations in clipped, dried, and weighed biomass. Consequently:

$$UPEBB_{m,t} = \left(UPFFREQ_{m,t}{}^2 + UAPB_{m,t}{}^2\right)^{1/2} \quad (38)$$

Where:

UPEBB = Uncertainty in project methane emissions from burning of biomass (%)

$$UPFFREQ_m = 3.84 \times 100 \times \frac{SD(PFFREQ_{m,Y})}{PFFREQ_m \times (Y\text{-}1)^{1/2}} \quad (39)$$

Where:

$UPFFREQ_m$ = Uncertainty in the project fire frequency in stratum *m* (%)

$PFFREQ_m$ = Mean proportion of area of stratum *m* burned during the Y years of the monitoring period

$SD(PFFREQ_{m,Y})$ = Standard deviation in project area of stratum *m* burned during the *Y* years of the monitoring period

$$UAPB_m = 3.84 \times 100 \times \frac{SD(APB_{m,Y})}{APB_m \times (Y-1)^{1/2}} \quad (40)$$

Where:

$UAPB_m$	= Uncertainty in mean within-stratum aboveground plant biomass at the end of the growing season in stratum *m* (%)
APB_m	= mean aboveground plant biomass at the end of the growing season (kg/m^2)
Y	= number of years in the monitoring period
3.84	= multiplier that converts the numerator into a 95% confidence interval
100	= multiplier that converts the expression into percent

8.4.2.2.3 Uncertainty In Project Soil Removals

Under a measured approach, uncertainty in soil sequestration, $UPRS_{m,t}$ in stratum *m* in year *t* is obtained from the 95 percent confidence interval, as required by the VCS rules[47, 49] of measured change in SOC across z_m sampling stations in stratum *m*.

$$UPRS_{m,t} = \frac{SD\Delta SOC_m \times 100 \times 3.84}{\Delta SOC_m \times (z_m - 1)^{1/2}} \quad (41)$$

Where:

$UPRS_{m,t}$	= uncertainty in project soil removals in stratum *m* at time *t* (%)

$$\Delta SOC_m = \sum_{j=1}^{z_m} \frac{SOC_{m,j,t} - SOC_{m,j,v}}{Y} \quad (42)$$

Where:

ΔSOC_m	= Mean of the difference in SOC between the beginning of the project or monitoring period, time *v*, and the year of monitoring *t*, across z_m sampling stations in stratum *m* (tC/ha)

$$SD\Delta SOC_m = \frac{SD\left(\Delta SOC_{m,z_m}\right)}{(z_m - 1)^{1/2}} \quad (43)$$

Where:

$SD\Delta SOC_m$	= Standard deviation of ΔSOC in stratum *m* during the monitoring period across z_m sampling stations in stratum *m*
Y	= Number of years in the monitoring period
z_m	= Number of sampling stations in stratum *m*
3.84	= Multiplier that converts the numerator into a 95% confidence interval
100	= Multiplier that converts the expression into percent

Under a modeled approach, $UPRS_{m,t}$ is obtained from the calculated 95 percent confidence interval, as required by the VCS[47, 49] from a Monte Carlo simulation of modeled changes in soil carbon (see Sections 8.4.2 and 8.1.3.3) averaged across *n model runs* in stratum *m*.

$$UPRS_{m,t} = 3.84 \times 100 \times \frac{SDMOD\Delta SOC}{MOD\Delta SOC \times (n-1)^{1/2}} \quad (44)$$

Where:

$UPRS_{m,t}$	= Uncertainty in project removals through increased soil carbon in stratum *m* at time *t* (%)
$SDMOD\Delta SOC_m$	= Standard deviation of more than 100 modeled SOC estimates for stratum *m* from Monte Carlo simulation.
$MOD\Delta SOC_m$	= Mean modeled project equilibrium SOC for stratum *m* from more than 100 simulations of project equilibrium SOC, (tC/ha)
n	= Number of times simulation is run (must be greater than 100)
3.84	= Multiplier to convert standard error into a 95% confidence interval
100	= Multiplier to convert to percent

8.4.2.2.4 Uncertainty In Project Emissions And Removals From Woody Plant Biomass

Uncertainty in emissions from loss or gain of aboveground woody plants $UPERWP_{m,t}$ arises from three sources: Consequently, uncertainty in removals or emissions from changes in aboveground woody plant biomass, $UPERWP_{m,t}$, must be calculated as follows:

$$UPERWP_{m,t} = \left(UAWPB_{m,t-1}{}^2 + UAWPB_{m,t}{}^2 + UWD_m{}^2\right)^{1/2} \quad (45)$$

Where:

$UPERWP_{m,t}$	= Uncertainty in project emissions and removals from woody plants in stratum *m* in year *t*
$UAWPB_{m,t-1}$	= Uncertainty in project emissions and removals from woody plant biomass in stratum *m* at the project start date or the previous (year = t-1)
$UAWPB_{m,t}$	= Uncertainty in project emissions and removals from woody plant biomass in stratum *m* in year *t-1*
UWD_m	= Uncertainty in wood density in stratum *m*

(1) Among plot variation in initial (baseline) aboveground woody plant biomass in stratum m, $UAWPB_{m,0}$

$$UAWPB_{m.0} = \frac{SD(AWPB_{m.z_m}) \times 100 \times 3.84}{AWPB_m \times (z_m - 1)^{1/2}} \quad (46)$$

Where:

$SD(AWPB_{m,zm})$	= Standard deviation of aboveground woody plant biomass across z_m sampling stations in stratum *m*.
$AWPB_m$	= Mean woody plant biomass across z_m sampling stations in stratum *m* (kg/m^2)
3.84	= Multiplier to convert expression to 95% confidence interval
100	= Multiplier to convert expression to percent

(2) Among plot variation in initial (baseline) aboveground woody plant biomass in year t of verification in stratum m: $UAWPB_{m,t}$,

$$UAWPB_{m,t} = \frac{SD(AWPB_{m,t,.z_m}) \times 100 \times 3.84}{AWPB_{m,t} \times (z_m - 1)^{1/2}} \quad (47)$$

$SD(AWPB_{m,t,zm})$ = standard deviation of aboveground woody plant biomass across z_m sampling stations in stratum *m* at time *t* since the project start or last verification.

$AWPB_{m,t}$ = mean woody plant biomass across z_m sampling stations in stratum *m* at time *t* since the project start or last verification (kg/m^2).

3.84 = multiplier to convert numerator to 95% confidence interval

100 =multiplier to convert expression to percent

and

(3) Among plot variation in wood density: UWD_m

$$UWD_m = \frac{SD(WD_{m.z_m}) \times 100 \times 3.84}{WD_m \times (z_m - 1)^{1/2}} \quad (48)$$

Where:

$SD(WD_{m,zm})$ = standard deviation of wood density across z_m sampling stations in stratum *m* at time *t* since the project start or last verification.

$WD_{m,}$ = mean wood density across z_m sampling stations in stratum *m* (g/cm^3)

3.84 = multiplier to convert expression to 95% confidence interval

100 = multiplier to convert expression to percent

8.4.2.2.5 Uncertainty in Leakage Emissions and Removals

If leakage is not negligible, uncertainty in leakage must be calculated as

$$ULE_t = \left(ULD_t{}^2 + ULM_t{}^2\right)^{1/2} \quad (49)$$

Where

ULE_t = uncertainty in total leakage (%)

ULD_t = uncertainty in displacement leakage (%)

ULM_t = uncertainty in market leakage (%)

$$ULD_t = UPRS_t \qquad (50)$$

Where:

$UPRS_t$ = Uncertainty in project removals due to changes in soil carbon stocks in year t (%).

This assumes that displacement leakage affects only soil carbon removals, and thus is subject to uncertainty associated with predicting impacts project activities on soil carbon removals

Uncertainty in market leakage, ULM_t, will be determined by using VCS module VMD0033 "Estimating emissions from market leakage."

8.4.2.3 Total Project Uncertainty

The total project uncertainty UT_t is calculated at the time of reporting through propagating the uncertainty in the baseline emissions and that in the project emissions and removals to year t:

Under a Monte Carlo calculation

$$UT_t = (UNR_t^2 + ULE_t^2)^{1/2} \qquad (51)$$

Where

UT_t = total project uncertainty (%)

UNR_t = uncertainty in net emissions and removals as calculated with Monte Carlo simulation (%)

ULE_t = uncertainty in leakage emissions and removals (%)

$$UT_t = \frac{((NR_t \times UNR_t)^2 + (LE_t \times ULE_t)^2)^{1/2}}{NR_t + LE_t} \qquad (52)$$

Where:

UT_t = Total project uncertainty (%)

UNR_t = Uncertainty in net emissions and removals, not including leakage (%)

ULE_t = Uncertainty in leakage emissions and losses from soil carbon stocks at time t (%)

NR_t = Net emissions reductions and removals at time t, not including leakage (tCO_2e)

LE_t = Leakage emissions and losses from soil carbon stocks at time t (tCO_2e)

8.4.3 Conservative Approach

Calculations of emissions reductions and removals are conservative because:

1) Baseline methane emissions use the harmonic mean for baseline emissions and an arithmetic mean for the project scenario leading to a conservative estimate for reductions in methane emissions (Section 8.1.3.1).

2) Initial baseline SOC level for modelled (activity-based) emission reductions must be the maximum of the previous 10 years, as required by the VCS rules[47, 49] . In the case of modeled approach, the baseline equilibrium SOC is set to this maximum and then compared to the modeled future equilibrium SOC (Section 8.1.3.3).

3) Because models used in the modeled approach must be validated for the project with data from the project area, no model correction is necessary. However, model predictions must meet the requirements for R^2, slope and intercept in a regression versus observed values (see section 8.1.3.3) to assure that the model does not overestimate removals. All parameter choices are to be conservative.

4) Emissions reductions are subject to reductions for uncertainty, as required by the VCS rules[47, 49] in the modeled approach, with uncertainty determined from 95 percent confidence intervals from standard errors calculated during Monte Carlo simulations (Section 8.4.2).

8.4.4 Uncertainty Deduction

If total project uncertainty in year *t*, based on 95 percent confidence intervals, $UT_t \leq$ 30 percent then no deduction must result for uncertainty.

If UT_t > 30 percent then the modified discounted value, $R_t = R_t^{disc}$ for net anthropogenic GHG removal by sinks to account for uncertainty must be:

$$R_t^{disc} = \frac{(100 - UT_t) \times R_t}{100} \quad (53)$$

Where:

R_t^{disc}	= Discounted net GHG emission reductions and removals by year *t* (tCO_2e)
UT_t	= Total project uncertainty
R_t	= Net GHG emission reductions and removals by year *t* (tCO_2e)

For *Y* years of the monitoring period,

$$R_Y = \sum_{t=1}^{d} R_t^{disc} + \sum_{t=1}^{u} R_t \quad (54)$$

Where:

d	= Number of years in which net removal must be discounted
u	= Number of years in which removals are not discounted
Y	= Number of years in the monitoring period *(d + u)*
R_t^{disc}	= Discounted net GHG emission reductions and removals by year *t* (tCO_2e)

R_t = Net GHG emission reductions and removals by year t (tCO_2e)

9 MONITORING

Given applicability conditions and allowable conservative exclusions, monitoring focuses on measuring the key parameters for calculating emissions and removals, demonstrating project management activities and measuring changes in SOC. The project activities key to changing methane emissions are altering the number and species composition of livestock grazing animals and/or species composition of forage plants , altering duration, timing, and intensity of grazing, and/or changing fire frequency, intensity and any accompanying vegetation change (such as in woody biomass). Changes in SOC density under the project scenario will also be monitored, and stratified according to management practices or soil and climatic conditions. Monitoring of soil, vegetation, grazing intensity and occurrence and intensity of fires will fully employ the permanent sampling stations discussed in Section 8.1.2.

9.1 Data and Parameters Available at Validation

9.1.1 Project Design

Data / Parameter	$PA_{m,g}$
Data unit	ha
Description	Project area in stratum m
Equations	3, 9, 11, 14 and 15
Source of data	Measured in project area
Justification of choice of data or description of measurement methods and procedures applied	Using shape files in a GIS or from known coordinates of stratum boundaries or from legal descriptions of the property included in the project area.

Comments	Project proponents must ensure that the following information in regards to the project area of each stratum is provided in the project description: 1) Map(s) of the locations of the permanent sampling plots overlaid on a map of project strata. 2) Results of cluster analysis to determine project strata. 3) Table of all project strata, their description, and area, PA_m 4) Results of analysis to determine the number of sampling units and their allocation among strata

Data Unit / Parameter	GWP_{CH4}
Data unit	t CO_2e/t CH_4
Description	Global-warming potential for CH_4
Equations	6, 8, 12, 30 and 32
Source of data	GWP_{CH4} must be obtained from the IPCC Second Assessment Report
Value applied	21
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of data	Calculation of baseline emissions Calculation of project emissions
Comment	

9.1.2 Baseline Methane Emissions

Data / Parameter	$W_{c,t}$
Data unit	kg
Description	Average body weight for animals of category c in year t
Equations	1
Source of data	Measured in project area
Justification of choice of data or description of measurement methods and procedures applied	Necessary to estimate emission factor for grazing animals using allometric equations in **Error! Reference source not found.**. Measurements must be taken in accordance with the procedures described in Section 9.1.2.
Purpose of data	Calculation of baseline emissions

Comments	

Data / Parameter	$N_{c,i}$
Data unit	number
Description	Baseline number of animals of category *c* in census *i*
Equations	1
Source of data	Measured in project area
Justification of choice of data or description of measurement methods and procedures applied	The number of animals in each census *i* must be measured to calculate the harmonic mean of the multiple counts i of n censuses of animals in category c. At least four measurements within the baseline period, with at least two during the period 5-10 years prior to the project start, must be available. Measurements must be taken in accordance with the procedures described in Section 9.1.2.
Purpose of data	Calculation of baseline emissions
Comments	The project description must provide a table of historical censuses or estimates of numbers of grazing animals, BN_c, for each year in which counts or estimates are available, sorted by the k categories of animals in the project area: species, breed (if applicable), sex, and age, plus the respective live body weights (W_c) of each category, with 95% percent CI and uncertainties). The project description must also provide a data table showing calculations of methane emissions based on the equations in **Error! Reference source not found.** for each animal category for each year that data are available. The table must include calculated total emissions for that year and a cell containing the harmonic mean of total annual calculated methane emissions. This will be the baseline BEM. The harmonic mean appropriately and conservatively weights the average methane emissions towards the lower values of a time series of measurements[27]. The table must also contain the uncertainty in daily methane emissions (from the regression equations in **Error! Reference source not found.**) and the harmonic mean and its' uncertainty. Table 5 below may be used as a template.

Table 5: Table for Calculating Baseline Methane Emissions from Animal Censuses.

Grazing Animal Category					Animal Counts (Head)						Methane Emissions	
Species	Sex/Age	Weight (kg)	Annual Methane Emissions/ Animal	Per Animal Uncertainty[1]	Year 1	Year 2	Year 3	Year 4	Harmonic Mean	Uncertainty in Animal Counts	Methane Emissions for Category (tCO_2e)	Uncertainty in Methane Emissions
Species 1												
Species 2												
Species 3												
Species 4												
										Total Emissions		

[1] Based on uncertainty in regression models that calculate methane emissions from body mass (see Table 3)

Species-specific weights on the left-hand side are used to calculate annual methane emissions per animal using equation 1 (section 8.1.3.1). Methane emissions per animal are then multiplied by the harmonic mean number of animals (equation 2) to estimate annual methane emissions for the animal category. Uncertainty per animal (from Table 3 in section 8.1.3.1) and uncertainty in the harmonic mean (equation 25 in section 8.4.2) combine in equation 27 to calculate overall uncertainty in methane emissions. This table must be included in the project description.

9.1.3 Parameters for Baseline Calculation of Emissions from Burning of Biomass

For projects that intend to increase fire frequency, the project description must show the equation (Equation 3) used to calculate BEBB and display a table showing estimated fire frequency $FFREQ_m$, initial unburned aboveground plant biomass ($APB_{m,b}$), with 95 percent CI and uncertainties (95 percent CI/estimate, expressed as a percentage) for each and calculated BEBB with for each project stratum.

Data / Parameter	$APB_{m,b}$
Data unit	kg dry mass/ha
Description	Mean total aboveground plant biomass in stratum m in year t at the end of the growing season (summer or wet season)
Equations	3
Source of data	Measured
Justification of choice of data or description of measurement methods and procedures applied	Measured at permanent sampling stations within each stratum *m* by clipping, drying (at 25-50 ^{o}C) and weighing aboveground vegetation from one or more small quadrats. Measured at the beginning of the dry season in the tropics or beginning of the cold or burning season in temperate climates. Must be measured in the project area 1-2 years before the project start date, or within the first year of the monitoring period and prior to the first prescribed burn if fire frequency is to be increased to manage vegetation to increase soil carbon.
Purpose of data	Calculation of baseline emissions
Comments	

Data / Parameter	$FFREQ_m$
Data unit	Dimensionless proportion
Description	Average proportion of area burned in stratum *m* in past 10 years
Equations	3
Source of data	Measured
Justification of choice of data or description of measurement methods and procedures applied	Measured by mapping burned areas with aerial photography or in projects with extensive area (> 10,000 ha), interpreting satellite images, such as MODIS, with published algorithms for assessing burned area[19]. Photography or satellite image interpretations must be verified by records of known burned areas or ground assessments of burns in the past year
Purpose of data	Calculation of baseline emissions
Comments	

Data / Parameter	BC_G
Data unit	kg biomass / kg biomass burned
Description	Baseline combustion factor for savanna/grassland
Equations	3

Source of data	Hoffa et. al., 1999 or Reference [41]
Value Applied	0.5 or default from Table 2.6, respectively
Justification of choice of data or description of measurement methods and procedures applied	It is unlikely that all aboveground biomass is combusted in fire, but this fraction is difficult to measure accurately during past years because biomass remaining after fire must be measured immediately following fire[42]. The fraction of biomass combusted usually averages around 0.75 [42] and setting BC_G = 0.5 makes the potential impact of increasing fire under the project scenario conservative in its likelihood to reduce emissions.
Purpose of data	Calculation of baseline emissions
Comments	

Data / Parameter	EF_{BG}
Data unit	g CH_4/kg biomass burned
Description	Emission factor for the burning of grassland
Equations	3, 9
Source of data	Reference [51]
Value Applied	1.9
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of data	Calculation of baseline emissions Calculation of project emissions
Comments	

9.1.4 Parameters for Calculation of Baseline SOC

A critical measurement is initial soil organic carbon which is necessary in establishing the baseline SOC in the measured approach and validating the chosen soil carbon dynamic model in a modeled approach. Multiple stations must be sampled within each stratum so as to determine a 95% percent confidence interval. Some models only quantify changes in SOC to specific depths, (eg, CENTURY only predicts SOC to a depth of 20 cm[16, 31]), and if using a modeling approach with a restricted depth, the project proponents must measure depth that matches that of the model. If using a measured approach or a model that allows different soil depths to be used, and appreciable soil carbon stocks occur below 30 cm[52], then proponents are justified in sampling deeper in the soil profile, even to a depth of 1m. Known volumes of soil from the cores must be sieved to remove rocks, pebbles, and coarse fragments, and then the remainder dried (5 days at 45°C or equivalent) and weighed to determine bulk density (Mg/m^3)[53].

If an IR spectrometer is to be used, the project proponent must show all calibration data in a table with spectral emissions and measurements of soils or plants and graphs showing the regressions of spectral data against measurements.

Data / Parameter	$DEPTH_{m,j,0}$
Data unit	cm
Description	Soil core depth at station *j* in stratum *m* at time *t = 0* (ie, at the start of the project or since the last verification)
Equations	4
Source of data	Measured in project area
Justification of choice of data or description of measurement methods and procedures applied	At each sampling station *j*, according to standard methods[52, 54], soil must be taken from at least 3 soil cores (with 10 cores at each site recommended to reduce uncertainty) to a depth that accounts for the vast majority (> 80 percent) of SOC in the soil column, reflects depth to hardpans or bedrock, or matches calculations from soil carbon models. Multiple cores may be well-mixed into a single composite sample for analysis.
Purpose of data	Calculation of baseline emissions
Comments	

Data / Parameter	$SOC\%_{j,m,0}$
Data unit	Dimensionless proportion
Description	Proportion soil organic carbon at station *j* in stratum *m* at time *t = 0* (ie, at the start of the project or since the last verification)
Equations	4
Source of data	Measured in project area
Justification of choice of data or description of measurement methods and procedures applied	The baseline for the measured offset approach is based on increasing SOC. Tracked at the level of j = 1 to z_m individual sampling stations in each stratum because offset will be based on demonstrating changes in SOC at individual stations and then summing increments. At each sampling station *j*, according to standard methods[52, 54], soil must be taken from at least 3 soil cores (with 10 cores at each site recommended to reduce uncertainty) to a depth that accounts for the vast majority (> 80 percent) of SOC in the soil column, reflects depth to hardpans or

	bedrock, or matches calculations from soil carbon models. Multiple cores may be well-mixed into a single composite sample for analysis. Multiple stations must be sampled within each stratum so as to determine a 95 percent confidence interval. Organic carbon concentrations must be measured in appropriate academic or industrial laboratories that use either chemical[55] combustion or appropriately calibrated spectral analysis methods. IR methods must be calibrated by regression, with R^2 $\geq$ 0.90, of IR measurement with measurement by chemical or combustion methods. Graphs of regression of IR versus combustion or chemical methods must be shown. There must be no significant bias (ie, slope 95 percent confidence interval must include 1) intercept 95 percent CI must include 0. Bias must be determined by evaluating percent bias (positive or negative) following equation (5) (see detailed description of bias evaluation in Section 8.1.3.3) and cannot exceed $\pm$ 10%. If an IR spectrometer is to be used, the project proponent must show all calibration data in a table with spectral emissions and measurements of soils or plants and graphs showing the regressions of spectral data against measurements.
Purpose of data	Calculation of baseline emissions
Comments	

Data / Parameter	$BULK_{m,j,0}$
Data unit	Mg/m^3 or, equivalently, g/cm^3
Description	Bulk density at station *j* in stratum *m* at time *t = 0* (i.e., at the start of the project or since the last verification)
Equations	4
Source of data	Measured in project area
Justification of choice of data or description of measurement methods and procedures applied	At each sampling station *j*, according to standard methods[52, 54], soil must be taken from at least 3 soil cores (with 10 cores at each site recommended to reduce uncertainty) to a depth that accounts for the vast majority (> 80 percent) of SOC in the soil column, reflects depth to hardpans or bedrock, or matches calculations from soil carbon models. Multiple cores may be well-mixed into a single composite sample for analysis.

	Known volumes of soil from the cores must be sieved to remove rocks, pebbles, and coarse fragments, and then the remainder dried (5 days at 45ºC or equivalent) and weighed to determine bulk density.[53]
Purpose of data	Calculation of baseline emissions
Comments	

9.1.5 Parameters for Soil Carbon Models

Soil carbon models may require anywhere from a few to more than 80 parameters, so there is no definitive list of parameters that would apply to all models. However, in evaluating whether a modeled approach is feasible or desirable, the following parameters are likely to be key inputs into soil carbon models. Each parameter may vary among strata, depending on the size of the project area and underlying variation in soil type and plant species composition. Parameters must yield a predicted SOC density.

Data / Parameter	MAP_m
Data unit	mm/yr
Description	Mean annual precipitation in stratum m
Equations	Model input
Source of data	Precipitation maps from government or peer-reviewed published sources, nearby weather stations, or rain gauges
Justification of choice of data or description of measurement methods and procedures applied	A key variable that affects a number of processes driving SOC
Purpose of data	Calculation of baseline emissions
Comments	

Data / Parameter	$ST_{j,m,y}$
Data unit	ºC
Description	Soil temperature at station j in stratum m in month y
Equations	Model input
Source of data	Measured in project area

Justification of choice of data or description of measurement methods and procedures applied	Must be measured monthly or at least seasonally with a digital thermometer with probes inserted to at least ½ the depth at which SOC will be sampled (ie, to 10 cm if soil will be sampled and modeled to 20 cm [16])
Purpose of data	Calculation of baseline emissions
Comments	

Data / Parameter	$SAND\%_{j,m}$ and/or $CLAY\%_{j,m}$ and/or $SILT\%_{j,m}$
Data unit	Dimensionless proportion expressed as percent
Description	Proportion of soil that is sand, silt, and or clay at station j in stratum m
Equations	Model input
Source of data	Measured in project area
Justification of choice of data or description of measurement methods and procedures applied	Soil collected to desired depth at each sampling station must be mixed, and subsample analyzed for clay, silt, and sand fractions in a professional laboratory. Some models require percent sand, some percent clay and some percent of all three particle classes, sand, silt and clay.
Purpose of data	Calculation of baseline emissions
Comments	

Data / Parameter	$GI_{j,m}$
Data unit	Dimensionless proportion
Description	Mean annual grazing intensity at station j in stratum m
Equations	Model input
Source of data	Measured
Justification of choice of data or description of measurement methods and procedures applied	Measured at each sampling station prior to validation by either 1) Comparing clipped biomass at least at the end of the growing season, or more frequently for some models, inside and outside small (1 m^2) fences. $GI_{j,m}$ = 1 – (biomass outside/biomass inside). Biomass is clipped, dried at 25 – 50 °C, and weighed. 2) Visually estimating historical grazing intensity from a calibrated observation method (R^2>0.80 correlation between measured GI (from option 1 above and

	observational method)) based on species composition, bare ground, and vegetation height.
Purpose of data	Calculation of baseline emissions
Comments	

Data / Parameter	$MAPLC_{j,m}$
Data unit	Dimensionless proportion
Description	Mean aboveground plant cellulose plus lignin at sampling plot j in stratum m
Equations	Model input
Source of data	Measured in project area
Justification of choice of data or description of measurement methods and procedures applied	SOC is often closely related to inputs of these forms of carbon because they resist microbial decomposition.
Purpose of data	Calculation of baseline emissions
Comments	

In addition, soil carbon models will likely use fire frequency, $FFREQ_m$ introduced in Section 8.1.3.2, and initial $SOC_{m,j,0}$ introduced in Section 8.1.3.4.

Tracking parameters at each sampling station allows the chosen soil carbon model(s) to be tested at many locations and under different conditions. This improves the ability to infer whether data fit model predictions.

These parameters must be input into the chosen soil carbon model(s) to calculate the SOC parameters described below, which are used in the quantification of removals.

Data / Parameter	$MSOC_{m,j,b}$
Data unit	tC/ha
Description	Modeled SOC at station *j* in stratum *m* for each year *b* during the baseline period
Equations	7
Source of data	SOC model

Justification of choice of data or description of measurement methods and procedures applied	SOC models applied must meet with the modeling requirements described in Section 8.1.3.4.
Purpose of data	Calculation of baseline emissions
Comments	

Data / Parameter	$PSOC^{eq}_{m,j,}$
Data unit	tC/ha
Description	Modeled SOC at equilibrium at station *j* in stratum *m*
Equations	13
Source of data	SOC model
Justification of choice of data or description of measurement methods and procedures applied	SOC models applied must meet with the modeling requirements described in Section 8.2.3.3.
Purpose of data	Calculation of project emissions
Comments	

Data / Parameter	D
Data unit	years
Description	Years required to achieve SOC equilibrium
Equations	13
Source of data	SOC model
Justification of choice of data or description of measurement methods and procedures applied	SOC models applied must meet with the modeling requirements described in Section 8.2.3.
Purpose of data	Calculation of project emissions
Comments	

9.1.6 Parameters for Removals from Woody Plant Biomass

Data / Parameter	C
Data unit	kg C/kg biomass
Description	Proportion of wood composed of carbon
Equations	15
Source of data	CDM, *A/R Methodological Tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities*, and MacDicken, 1997
Value applied	0.45
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of data	Calculation of project emissions
Comments	

9.2 Data and Parameters Monitored

Parameters monitored are those needed to calculate removals from reduced methane emissions from animals and/or removals from soil carbon sequestration plus any increases in emissions of methane from burning of biomass and leakage.

Data / Parameter	$PA_{m,t}$
Data unit	ha
Description	Project area in stratum m in year t
Equation	12, 14, 18, 19
Source of data	Measured in project area
Description of measurement methods and procedures to be applied	Using shape files in a GIS or from known coordinates of stratum boundaries or from legal descriptions of the property included in the project area.
Frequency of monitoring/recording	Annual
QA/QC procedures to be applied	Areas must be determined from accurate GIS layers of classified project area or from legal descriptions of property included in the project area. Verification should be with Global Positioning

	Systems (GPS) with an accuracy of 10 m or less. Ground points may include permanent sampling stations but also may be necessary to include points at defined stratum boundaries or along roads.
Purpose of data	Calculation of project emissions
Comments	Projects must ensure that the following information in regards to the project area of each stratum is provided within the relevant area of the project description: 1) Map(s) of the locations of the permanent sampling plots overlaid on a map of project strata. 2) Results of cluster analysis to determine project strata. 3) Table of all project strata, their description, and area, PA_m 4) Results of analysis to determine the number of sampling units and their allocation among strata

9.2.1 Project Animal Methane Emissions

Unlike when determining the baseline, the arithmetic mean of the counts during the project crediting period must be used to ensure a conservative estimate of reductions in methane emissions relative to baseline emissions, which are calculated with the harmonic mean[27].

For permissible methods of conducting an animal census, see Section 9.3.3.

Data / Parameter	$PN_{c,t}$
Data unit	number
Description	Mean number of animals of category c in the project area during year t
Equation	8, 17, 18
Source of data	Measured in project area
Description of measurement methods and procedures to be applied	Measured as the arithmetic mean of one or more years' animal censuses during the verification period
Frequency of monitoring/recording	Annual
QA/QC procedures to be applied	Based on records of livestock numbers, interviews of grazing managers, coordinators, herders or other administrative staff. Records should be kept as paper and electronic copies,

Purpose of data	Calculation of project emissions
Comments	The project description must provide a table, similar to that for calculating baseline methane emissions, of counts or estimates of numbers of grazing animals, PN_c, for each year during the monitoring period, sorted by the k categories in the project area: species, breed (if applicable), sex, and age, plus the respective live body weights (W_c) of each category, with 95% percent CI and uncertainties. The table must also contain the uncertainty in daily methane emissions and the uncertainty in the arithmetic mean count based on the equations in Section 8.4.2.2.1. Table 6 below may be use as a template.

Table 6: Table for Calculating Project Methane Emissions from Animal Censuses.

Grazing Animal Category					Animal Census (Number of Animals)						Methane Emissions	
Species	Sex/Age	Weight (kg)	Annual Methane Emissions/ Animal	Per Animal Uncertainty[1]	Year 1	Year 2	Year 3	Year 4	Arithmetic Mean	Uncertainty in Animal Counts	Methane Emissions for Category (tCO_2e)	Uncertainty in Methane Emissions
Species 1												
Species 2												
Species 3												
Species 4												
										Total Emissions		

[1] Based on uncertainty in regression models that calculate methane emissions from body mass (see Table 3)

Species-specific weights on the left-hand side are used to calculate annual methane emissions per animal using equation 1 (section 8.1.3.1). Methane emissions per animal are then multiplied by the arithmetic mean number of animals to estimate annual methane emissions for the animal category. Uncertainty per animal (from Table 3 in section 8.1.3.1) and uncertainty in the harmonic mean (equation 25 in section 8.4.2) combine in equation 27 to calculate overall uncertainty in methane emissions. This table must be included in the project description.

9.2.2 Project Emissions from Burning of Biomass

For projects that intend to increase fire frequency, the project description must show the equation (Equation (3)) used to calculate $PEBB_{m,t}$ at time *t* for each project stratum. All projects that alter fire frequency must and display a table showing estimated fire frequency $PFFREQ_{m,t}$ in year *t*, pre-fire aboveground plant biomass ($APB_{j,m,t}$), and post-fire aboveground plant biomass at stations where fire occurred ($APB_{j,m,f}$) with 95 percent CI and uncertainties for each and calculated.

Data / Parameter	$PFFREQ_{m,t}$
Data unit	Dimensionless proportion
Description	Average proportion of area burned in stratum *m* during project year t.
Equations	9
Source of data	Measured
Description of measurement methods and procedures to be applied	Measured by mapping burned areas with aerial photography or in projects with extensive area (> 10,000 ha), interpreting satellite images, such as MODIS with published algorithms for assessing burned area[19]. Photography or satellite image interpretations must be confirmed by records of known burned areas or ground assessments of burns in the past year.
Frequency of monitoring/recording	Every 15 days during the burning season
QA/QC procedures to be applied	Follow procedures in references [18, 19]
Purpose of data	Calculation of project emissions
Comments	

Data / Parameter	$APB_{j,m,t}$
Data unit	kg dry mass/ha
Description	Aboveground plant biomass at station *j* in stratum *m* in year *t* at the beginning of the dry/cold or burning season
Equations	9,10
Source of data	Measured
Description of measurement methods and procedures to be applied	Measured at permanent sampling stations within each stratum m by clipping, drying (at 25-50 ºC) and weighing aboveground vegetation from one or more small quadrats. Measurements from all quadrats must be averaged for each sampling station *j*. Measured at the beginning of the dry/cold/burning season in temperate climates[17, 56].

Frequency of monitoring/recording	Annually
QA/QC procedures to be applied	Samples must be dried in a professional drying oven for 3 days at 45-60ºC or be air-dried in sunshine for 4-7 days to a constant mass
Purpose of data	Calculation of project emissions
Comments	

Data / Parameter	$APB_{j,m,f}$
Data unit	kg dry mass/ha
Description	Aboveground plant biomass in stratum *m* in year *t* at immediately after fire
Equations	10
Source of data	Measured
Description of measurement methods and procedures to be applied	Measured at permanent sampling stations within each stratum m by clipping, drying (at 25-50 ºC) and weighing aboveground vegetation from one or more small quadrats. Measurements from all quadrats must be averaged for each sampling station *j*. Measured immediately following the occurrence of fire[17, 56].
Frequency of monitoring/recording	Once in 1-2 years prior to project start or before the first prescribed burn in the first year of the project
QA/QC procedures to be applied	Samples should be dried in a professional drying oven for 3 days at 45-60ºC or be air-dried in sunshine for 4-7 days to a constant mass
Purpose of data	Calculation of project emissions
Comments	

9.2.3 Parameters for Calculating SOC Removals

If a measured approach is taken, then the critical measurement is of SOC density at the end of the monitoring period at each sampling station, according to standard methods[52, 54]. Soil must be taken from three or more pooled soil cores (with 10 cores at each site recommended to reduce uncertainty) at each station to a desired depth (cm) For more details, see section 9.1.4

In a modeled approach, these same procedures must apply when monitoring soil carbon for the purposes of re-calibrating the chosen soil carbon model. In this case there may be a calibration period of Z years (typically 5-7 years) that is long enough to detect changes in SOC and likely longer than the monitoring periods used in a modeled approach.

Data / Parameter	$DEPTH_{m,j,t}$
Data unit	cm
Description	Soil core depth at station *j* in stratum *m* at time *t = 0* (ie, at the start of the project or since the last verification)
Equations	12
Source of data	Measured in project area
Description of measurement methods and procedures to be applied	Soil must be taken from at least three soil cores (with 10 cores at each site recommended to reduce uncertainty) at each station *j* to a depth that accounts for the vast majority (> 80 percent) of SOC in the soil column, reflects depth to hardpans or bedrock, or matches calculations from soil carbon models. Multiple cores may be well-mixed into a single composite sample for analysis.
Frequency of monitoring/recording	At the end of the monitoring period for measured approach projects, or, for modeled approach, after a desired monitoring period for re-calibrating the chosen soil carbon model on the basis of its ability to predict changes in soil carbon during the monitoring period.
QA/QC procedures to be applied	Depth cored must be the same as for baseline soil carbon sampling (see 9.1.5). However, the depth used in calculating SOC after Y years of project activities must be adjusted to account for changes in bulk density such that $DEPTH_{m,j,Y}$ x $BULK_{m,j,Y}$ = $DEPTH_{m,j,0}$ x $BULK_{m,j,0}$. This ensures that equal masses of soil are compared between year 0 and year Y
Purpose of data	Calculation of project emissions
Comments	

Data / Parameter	$SOC\%_{m,j,t}$
Data unit	Dimensionless proportion
Description	Proportion soil organic carbon at station *j* in stratum *m* at time *t*
Equations	12
Source of data	Measured in project area

Description of measurement methods and procedures to be applied	Soil must be taken from at least three soil cores (with 10 cores at each site recommended to reduce uncertainty) at each station *j* to a depth that accounts for the vast majority (> 80 percent) of SOC in the soil column, reflects depth to hardpans or bedrock, or matches calculations from soil carbon models. Multiple cores may be well-mixed into a single composite sample for analysis. The organic carbon concentrations must be measured in appropriate academic or industrial laboratories with chemical[55] automated, calibrated analytical machines or with project-area calibrated infra-red IR spectrometers[30].
Frequency of monitoring/recording	At the end of the monitoring period for measured approach projects, or, for modeled approach, after a desired monitoring period for re-validating the chosen soil carbon model on the basis of its ability to predict changes in soil carbon during the monitoring period.
QA/QC procedures to be applied	The organic carbon concentrations must be measured in appropriate academic or industrial laboratories with chemical[55] automated, calibrated analytical machines or with project-area calibrated infra-red IR spectrometers[30]. IR methods must be calibrated by regression, with $R^2 \geq 0.90$, of IR measurement with measurement by chemical or combustion methods. Graphs of regression of IR versus combustion or chemical methods must be shown. There must be no significant bias (ie, slope 95 percent confidence interval must include 1) intercept 95 percent CI must include 0, which will ensure that MBIAS, following equation (5) [37] is between -10% and +10%. If an IR spectrometer is to be used, the project proponent must show all calibration data in a table with spectral emissions and measurements of soils or plants and graphs showing the regressions of spectral data against measurements.
Purpose of data	Calculation of project emissions
Comments	

Data / Parameter	$BULK_{m,j,t}$
Data unit	Mg/m^3, or, equivalently, g/cm^3
Description	Bulk density in stratum m, station j, year t
Source of data	Measured in project area
Equations	12

Description of measurement methods and procedures to be applied	Soil must be taken from at least three soil cores (with 10 cores at each site recommended to reduce uncertainty) at each station *j* to a depth that accounts for the vast majority (> 80 percent) of SOC in the soil column, reflects depth to hardpans or bedrock, or matches calculations from soil carbon models. Multiple cores may be well-mixed into a single composite sample for analysis. Known volumes of soil from the cores must be sieved to remove rocks, pebbles, and coarse fragments, and then the remainder dried (5 days at 45ºC or equivalent) and weighed to determine bulk density.
Frequency of monitoring/recording	At the end of the monitoring period for measured approach projects, or, for modeled approach, after a desired monitoring period for re-validating the chosen soil carbon model on the basis of its ability to predict changes in soil carbon during the monitoring period.
QA/QC procedures to be applied	However, the depth used in calculating SOC after Y years of project activities must be adjusted to account for changes in bulk density such that $DEPTH_{m,j,Y}$ x $BULK_{m,j,Y}$ = $DEPTH_{m,j,0}$ x $BULK_{m,j,0}$. This ensures that equal masses of soil are compared between year 0 and year Y [53]
Purpose of data	Calculation of project emissions
Comments	

9.2.4 Parameters for Project Soil Carbon Models

If using the modeled approach, the same soil carbon model used to calculate BSOC must be used to calculate SOC expected after Y years of management under the project scenario. Uncertainties again must be calculated with Monte Carlo simulations[3, 38].

It is crucial that model input parameters must be tracked at each sampling station if possible to allow the chosen soil carbon model(s) to be most responsive to variation in major inputs to the model. The model must predict SOC density from the parameters measured and used in the model.

At verification, the project proponent must provide a list of parameters for each station under the project scenario in year t, using the VCS table format for each. These parameters will vary among models, so an exhaustive list cannot be provided. However each parameter in the model must be listed, along with its uncertainty based on a 95 percent confidence interval, so that uncertainty calculations, following the Monte Carlo procedures in 8.4.2 may be verified. For example:

Data / Parameter	$MAP_{m,Y}$

Data unit	mm/yr
Description	Mean annual precipitation in stratum m over the project crediting period Y years.
Equation	Model input
Source of data	Precipitation maps or nearby weather stations
Description of measurement methods and procedures to be applied	A key variable that affects a number of processes driving SOC
Frequency of monitoring/recording	Annually if obtained from government sources or local weather stations, Daily if collected on the project area
QA/QC procedures to be applied	Data should be obtained from government sources or local official weather stations, or, if not available, from weather data collected on the project area.
Purpose of data	Calculation of project emissions
Comments	

Data / Parameter	$ST_{j,m,Z}$
Data unit	ºC
Description	Soil temperature at station j in stratum m in month Z
Equation	Model input
Source of data	Measured in project area
Description of measurement methods and procedures to be applied	Must be measured with a digital thermometer with probes inserted to at least ½ the depth at which SOC will be sampled (ie, to 10 cm if soil will be sampled and modeled to 20 cm[3, 16])
Frequency of monitoring/recording	At least monthly
QA/QC procedures to be applied	Procedures must follow those in references [57, 58]
Purpose of data	Calculation of project emissions
Comments	

Data / Parameter	$GI_{j,m,z}$
Data unit	Dimensionless proportion
Description	Mean annual grazing intensity at station j in stratum m in year t
Equation	Model input
Source of data	Measured in project area
Description of measurement methods and procedures to be applied	Measured at each sampling station at least twice each growing season prior to verification by comparing clipped biomass at least at the end of the growing season, or more frequently for some models, inside and outside small (1 m^2) fences. GI_m = 1 – (biomass outside/biomass inside). Biomass is clipped, dried at 25 – 50 ^oC, and weighed.
Frequency of monitoring/recording	Must be at least twice per year, but preferably monthly, particularly in tropical project areas where plant growth can occur in any month
QA/QC procedures to be applied	Samples should be dried in a professional drying oven for 3 days at 45-60^{o}C or be air-dried in sunshine for 4-7 days to a constant mass, following references [2, 17, 56]
Purpose of data	Calculation of project emissions
Comments	

In addition, soil carbon models for the project scenario will likely use project fire frequency, $PFFREQ_{m,t}$ or the frequency of fire (proportion area burned) in stratum m during year t (section Section 9.2.2), and initial $SOC_{m,j,0}$ introduced in Section 8.1.3.4.

9.2.5 Parameters for Project Removals from Woody Plant Biomass

The two principal parameters are the initial and verified aboveground woody plant biomasses. Uncertainty is expressed as 95% percent CI/mean for each recorded difference in biomass at each of the permanent sampling stations.

Data / Parameter	$AWPB_{m,j,0}$
Data unit	kg/ha
Description	Aboveground woody plant biomass at the project start or the year of last verification at station j and stratum m in the beginning of the monitoring period
Equations	15
Source of data	Measured in permanent sampling plots

Description of measurement methods and procedures to be applied	Circular quadrats centered at each permanent sampling station *j* must be sampled for number and diameter at breast height (dbh) of each woody stem within a specified diameter. Radius must be 5-50 cm depending on woody stem density, with smaller radii appropriate for more dense woody vegetation[45, 59].
Frequency of monitoring/recording	During the beginning of the monitoring period
QA/QC procedures to be applied	Procedures must follow those detailed in reference [46]
Purpose of data	Calculation of project emissions
Comments	

Data / Parameter	$AWPB_{m,j,Y}$
Data unit	kg/ha
Description	Aboveground woody plant biomass at station j and stratum m in year Y at the end of the monitoring period
Equations	15
Source of data	Measured in project area at permanent sampling stations
Description of measurement methods and procedures to be applied	Circular quadrats centered at each permanent sampling station *j* must be sampled for number and dbh of each woody stem within a specified diameter. Radius must be 5-50 m depending on woody stem density, with smaller radii appropriate for more dense woody vegetation[45, 59].
Frequency of monitoring/recording	Once at the end of the monitoring period
QA/QC procedures to be applied	Procedures must follow those detailed in reference [46]
Purpose of data	Calculation of project emissions
Comments	

9.2.6 Parameters for Leakage

Data / Parameter	$DN_{C,x}$
Data unit	head
Description	Number of livestock of each category *c* that were outside the project area (outside the fence defining the boundary of the

	project area, or, in the case of open grazing lands eg pastoralist areas, beyond 2 km from the mapped project area boundary on day *x*
Equations	17,18
Source of data	Measured
Description of measurement methods and procedures to be applied	Determined from records of livestock distributions, as recorded from interviews with grazing managers, coordinators, herders, or other administrative staff. For additional details see Section 9.3.3
Frequency of monitoring/recording	Monthly
QA/QC procedures to be applied	Records should be kept as paper and electronic copies
Purpose of data	Calculation of leakage
Comments	

Data / Parameter	d
Data unit	days
Description	Total number of days livestock were off the project area
Equations	17,18
Source of data	Measured
Description of measurement methods and procedures to be applied	Based on records of livestock numbers and their distribution on and off the project area, based on interviews of grazing managers, coordinators, herders or other administrative staff. For additional details see Section 9.3.3
Frequency of monitoring/recording	Monthly
QA/QC procedures to be applied	Records should be kept as paper and electronic copies, with at least one electronic copy kept off the project as an online database
Purpose of data	Calculation of leakage
Comments	

9.3 Description of the Monitoring Plan

9.3.1 Sampling Design

The sampling design of the permanent sampling stations and their division among strata is described in detail in Section 8.1.2.

9.3.2 Impact of Project Activities

Additionality of greenhouse gas reductions arises from the implementation of new management activities, and it is important for the project proponent to monitor the effectiveness of these new activities. Activities fall principally into three major categories: (1) manipulating animal numbers and grazing intensity, (2) managing fire, (3) changing plant species composition and/or lignin and cellulose content.

9.3.3 Animal Numbers

The different methods of animal censuses are reviewed by Seber[60]. The preferred methods are:

1) *Ownership records* in cases where individual records exist for each animal owned by the project proponent or participants. This is the most accurate measure of animal numbers, but is likely to only be possible in developed countries where such records can be created and maintained.

2) *Corral counts*, in which all known corrals or “bomas” where animals are kept at night are identified to category c and counted. The advantage of this method is that it allows a total census as long as all corrals can be located and censused. This may be the superior method for censusing animals kept by pastoralists in less developed countries. Care must be taken to census at times when animals are not being herded long distances to find new pasture or water, as the census may significantly underestimate animal counts. 95 percent confidence intervals may be estimated by repeated counts, comparison of counts among different observers, or subsampling methods like bootstrapping[61].

3) *Ground transect counts*, whereby transects are walked or driven and the number of animals of each category c, at distances measured with rangefinders, are counted. The area sampled by transects (length by mean observation distance) must cover at least 20 percent of the project area[60] to avoid unacceptable variance and uncertainty. Counts must be converted to density and multiplied by area to estimate total animal numbers in each category and their 95 percent confidence intervals by using the program DISTANCE[62]. Transects must be sampled in at least four years of the ten prior to the project start and at least twice per year during the project crediting period Y years. The advantage of this method is that it may be applied to wildlife or to livestock censuses in regions where livestock are not sedentary. The disadvantage is that animals are often aggregated across the landscape, which may greatly increase the variance of the

estimate, animals counted must be extrapolated to get totals for the project area, and accurate classifications of animals into categories may be inaccurate.

4) *Human surveys*, in which animal owners are interviewed about animal numbers of each category, kept in their corrals in the past. At least 30 individuals or 10 percent of the total animal holders in the project area, whichever is greater, must be interviewed. The advantage of this method is that more detail about breeds and weights may be incorporated into the determination of categories and estimation of methane emissions. The disadvantage is that the subsample of animals owned by the people interviewed must be extrapolated to encompass the project area, with accompanying uncertainty.

5) *Aerial surveys* in which animals of each category are counted from aerial photographs. This is a popular method among governments who are satisfied with broad surveys, but typically the uncertainty in aerial surveys is too large to be used with daily methane emissions, which are already plagued with relatively large uncertainties. Typically aerial surveys only work for cattle or other similarly large animals (eg, camels and horses), as sheep and goats are usually too small to be differentiated by species, sex or age from the air. Also, uncertainties for aerial surveys may be prohibitive, as they often exceed 50 percent[60].

9.3.4 Grazing Intensity

The project proponent must be prepared to measure aboveground plant biomass at least semi-annually to determine the impacts of grazing on vegetation throughout the project area. The parameter $GI_{m,j,t}$ represents the percent difference in standing crop between grazed and ungrazed (fenced) vegetation. It may be measured at all permanent sampling stations by comparing aboveground plant biomass, $APB_{j,m,t}$ at each station with biomass inside small fences (0.67 – 2 m^2). Herbaceous and shrub biomass must be clipped from three or more small quadrats at each station and from two or more small (0.67 - 2 m^2) temporary fenced quadrats (utilization cages). Grazing intensity (GI) is 1 – (biomass unfenced/biomass fenced)[17]. Cages must be moved after clipping to ensure that the station measures grazer use of plant production over each season or portion of a season. It may also be measured using calibrated satellite imagery (with at least $R^2 > 0.60$ between the satellite index and measured biomass on the ground) by comparing vegetation indices, such as NDVI or EVI[31, 63], between ungrazed and grazed pixels paired to have similar soil types, precipitation, and other variables.

9.3.5 Fire Frequency

Baseline proportion of area burned ($FFREQ_{m,b}$) and project proportion of area burned during the project crediting period Y requires demonstration of the occurrence and area covered by fires over a period of 10 years for the baseline and Y years for the project scenario. Acceptable information sources include aerial photographs or interpreted satellite images with a resolution (pixel length in m) smaller than 0.5 percent of the square root of the total project area (in m^2)[18, 19]. An example method is Dempewolf's et al. (2007)[19] algorithm, now employed as MODIS Burned

Area images dating back to 2000. These images use red and infra-red spectral information from 15 day composite images, which eliminate clouds and shadows, from MODIS satellites[12] to calculate a BAI, or burned area index that provided 85-95 percent accuracy in classifying image pixels as burned or unburned in East African grassland and savanna. Other methods of image interpretation, particularly aerial photographs, may be used. Any method must be tested by comparing pixels in classified images with observations of burned or unburned during the same time window in the permanent sampling stations. Valid interpretation methods must commit less than 12 percent combined omission and commission errors[19].

9.3.6 Plant Species Composition

A key input variable affecting soil carbon dynamics and soil carbon models is species composition, as management practices to restore soil carbon will likely do so in part by changing plant species composition[32, 64, 65]. Replacement of woody shrubs or annual grasses that dominate under baseline conditions with perennial grasses with deep root systems under the project scenario can lead to rapid carbon sequestration. Tracking plant species composition is possible by measuring aerial cover of the four most dominant species each of grasses, herbs (dicotyledonous plants, wildflowers), and woody plants. Such data can show shifts as a consequence of new management activities.

9.3.7 Plant Lignin and Cellulose

Shifts in species composition may be accompanied by shifts in plant chemical composition that greatly affect calculations of some soil carbon models and measureable soil carbon sequestration. SOC is often closely related to inputs of these forms of carbon because they resist microbial decomposition. Plant cellulose and lignin (MAPLC) may be measured by either: 1) the Van Soest method of sequential digestion of ground plant material (clipped during the measurement of aboveground plant biomass (APB)) in acid detergent and sulfuric acid[66] in a professional laboratory, or 2)with infra-red (IR) spectrometers calibrated to project area plants and soils.

9.3.8 Ex Ante Leakage and Other Emission Sources

Leakage is mainly possible from net transfers of livestock out of the project area, which is not allowed by the applicability conditions but nevertheless must be monitored by inventorying livestock shipping depots and from censuses and interviews with inhabitants of the project area. Close monitoring and census efforts are especially needed during dry seasons or other periods when there may be strong motivation to move animals off the project area. Animal censuses must be timed to coincide with the greatest risk of animal movement to have the greatest chance to track any possible leakage**.**

[12] http://modis.gsfc.nasa.gov/

The possible but unlikely source of new emissions as a result of the project is the increase in the use of fossil fuels during vehicle and airplane use associated with management activities. These may be tracked with mileage logs in all project and associated vehicles and converted with IPCC 2000 emission factors[67] as stratified by the type of vehicle and fuel type (eg, diesel, gasoline, kerosene), to determine whether fossil fuel use approaches being a significant greenhouse gas source associated with project activity.

10 REFERENCES

1. Neary, D.G., et al., *Fire effects on belowground sustainability: a review and synthesis.* Forest Ecology and Management, 1999. **122**: p. 51-71.

2. Ritchie, M.E., *Plant compensation to grazing and soil carbon dynamics in a tropical grassland* PeerJ, 2014. **2**: p. e233.

3. Ogle, S.M., et al., *Scale and uncertainty in modeled soil organic carbon stock changes for US croplands using a process-based model.* Global Change Biology, 2010. **16**(2): p. 810-822.

4. Paustian, K., W.J. Parton, and J. Persson, *Modeling soil organic-matter in inorganic-amended and nitrogen-fertilized long-term plots. .* Soil Science Society of America Journal, 1992. **56**: p. 476-488.

5. IPCC, *Emissions from livestock and dung management*, in *Guidelines for Nartional Greenhouse Gas Inventories*. 2006, IPCC. p. 1-85.

6. Holdo, R.M., et al., *A disease-mediated trophic cascade in the Serengeti and its implications for ecosystem C.* PLoS Biology, 2009. **7** (9).

7. IPCC, *Grasslands*, in *Guidelines for Greenhouse Gas Inventories*. 2006, IPCC. p. 1-49.

8. Cantarel, A.A.M., et al., *Effects of Climate Change Drivers on Nitrous Oxide Fluxes in an Upland Temperate Grassland.* Ecosystems, 2011. **14**(2): p. 223-233.

9. Rafique, R., D. Hennessy, and G. Kiely, *Nitrous Oxide Emission from Grazed Grassland Under Different Management Systems.* Ecosystems, 2011. **14**(4): p. 563-582.

10. Liu, C.Y., et al., *Growing season methane budget of an Inner Mongolian steppe.* Atmospheric Environment, 2009. **43**(19): p. 3086-3095.

11. Saggar, S., et al., *Soil-atmosphere exchange of nitrous oxide and methane in New Zealand terrestrial ecosystems and their mitigation options: a review.* Plant and Soil, 2008. **309**(1-2): p. 25-42.

12. Liu, Z.Y., et al., *Comparison of vegetation indices and red-edge parameters for estimating grassland cover from canopy reflectance data.* Journal of Integrative Plant Biology, 2007. **49**(3): p. 299-306.

13. Ren, H.R., G.S. Zhou, and X.S. Zhang, *Estimation of green aboveground biomass of desert steppe in Inner Mongolia based on red-edge reflectance curve area method.* Biosystems Engineering, 2011. **109**(4): p. 385-395.

14. Kery, M., et al., *Trend estimation in populations with imperfect detection.* Journal of Applied Ecology, 2009. **46**(6): p. 1163-1172.

15. Porteus, T.A., S.M. Richardson, and J.C. Reynolds, *The importance of survey design in distance sampling: field evaluation using domestic sheep.* Wildlife Research, 2011. **38**(3): p. 221-234.

16. Pineiro, G., J.M. Paruelo, and M. Oesterheld, *Potential long-term impacts of livestock introduction on carbon and nitrogen cycling in grasslands of Southern South America.* Global Change Biology, 2006. **12**(7): p. 1267-1284.

17. McNaughton, S.J., *Ecology of a grazing ecosystem: the Serengeti.* Ecological Monographs, 1985. **55** p. 259-294.

18. De Santis, A., et al., *Mapping burn severity and burning efficiency in California using simulation models and Landsat imagery.* Remote Sensing of Environment, 2010. **114**(7): p. 1535-1545.

19. Dempewolf, J., et al., *Burned-area mapping of the Serengeti-Mara region using MODIS reflectance data.* IEEE Geoscience and Remote Sensing Letters, 2007. **4**(2): p. 312-316.

20. CDM, *A/R methodological tool: Calculation of the number of sample plots for measurements within A/R CDM project activities, version 2*. 2009, UNFCCC Annex 19 EB 46 p. 7.

21. Petersen, R.G. and L.D. Calvin, *Sampling.* , in *Methods of Soil Analysis, Part 3: Chemical Methods*, D.L. Sparks, Editor. 1996, Soils Science Society of America: Madison, Wisconsin USA. p. 1-19.

22. Post, W.M., et al., *Monitoring and verifying changes of organic carbon in soil.* Climatic Change, 2001. **51**(1): p. 73-99.

23. Goidts, E., B. van Wesemael, and K. Van Oost, *Driving forces of soil organic carbon evolution at the landscape and regional scale using data from a stratified soil monitoring.* Global Change Biology, 2009. **15**(12): p. 2981-3000.

24. McNab, W.H., et al., *An unconventional approach to ecosystem unit classification in western North Carolina, USA.* Forest Ecology and Management, 1999. **114**(2-3): p. 405-420.

25. VCS, *Methods for stratification of the project area (X-STR), v1.0*. 2012, Verified Carbon Standard. p. 15.

26. Franz, R., et al., *Methane production in relation to body mass of ruminants and equids.* Evolutionary Ecology Research, 2010. **12**(6): p. 727-738.

27. Ferger, W.F., *The nature and use of the harmonic mean.* Journal of the American Statistical Association, 1931. **26**: p. 36-40.

28. Archimede, H., et al., *Comparison of methane production between C3 and C4 grasses and legumes.* Animal Feed Science and Technology, 2011. **166-67**: p. 59-64.

29. Brye, K.R. and N.A. Slaton, *Carbon and nitrogen storage in a typic Albaqualf as affected by assessment method.* Communications in Soil Science and Plant Analysis, 2003. **34**(11-12): p. 1637-1655.

30. Knadel, M., A. Thomsen, and M.H. Greve, *Multisensor on-the-go mapping of soil organic carbon content.* Soil Science Society of America Journal, 2011. **75**(5): p. 1799-1806.

31. Feng, X.M. and Y.S. Zhao, *Grazing intensity monitoring in Northern China steppe: Integrating CENTURY model and MODIS data.* Ecological Indicators, 2011. **11**(1): p. 175-182.

32. Izaurralde, R.C., et al., *Simulating soil C dynamics with EPIC: Model description and testing against long-term data.* Ecological Modelling, 2006. **192**(3-4): p. 362-384.

33. Williams, J.R., et al., *The EPIC crop growth model.* Transactions of the ASAE, 1989. **32**(2): p. 497-511.

34. Arah, J.R.M., et al., *Simulating trends in soil organic carbon in long-term experiments using the ITE (Edinburgh) Forest and Hurley Pasture ecosystem models.* Geoderma, 1997. **81**(1-2): p. 61-74.

35. Thornley, J.H.M. and M.G.R. Cannell, *Temperate grassland responses to climate change: An analysis using the Hurley pasture model.* Annals of Botany, 1997. **80**(2): p. 205-221.

36. Greenwood, J.A. and M.M. Sandomire, *Sample size required for estimating the standard deviation as a percent of its true value.* US Navy Research, 1950. **Paper 34**.

37. Moriasi, D.N., et al., *Model evaluation guidelines for systematic quantification of accuracy in watershed simulations.* Transactions of the American Society of Agricultural and Biological Engineers, 2007. **50**: p. 885-900.

38. Ortiz, C., et al., *Modelling soil carbon development in Swedish coniferous forest soils-An uncertainty analysis of parameters and model estimates using the GLUE method.* Ecological Modelling, 2011. **222**(17): p. 3020-3032.

39. Smith, P., et al., *A comparison of the performance of nine soil organic matter models using datasets from seven long-term experiments.* Geoderma, 1997. **81**(1-2): p. 153-225.

40. Burnham, K.P. and D.R. Anderson, *Multi-model inference: understanding AIC and BIC in model selection.* Sociological Methods and Research, 2004. **33**: p. 201-304.

41. IPCC, *Guidelines for National Greenhouse Gas Inventories* 2006. **4**(Chapter 2).

42. Hoffa, E.A., et al., *Seasonality of carbon emissions from biomass burning in a Zambian savanna.* Journal Of Geophysical Research, 1999. **104**: p. 13841-13853.

43. IPCC, *Quantifying uncertainties in practice. Ch 6*, in *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* R. Odingo, Editor. 2006, IPCC.

44. Microsoft. *Monte Carlo Simulation for Excel*. 2006; Available from: http://excelmontecarlo.com/.

45. CDM, *A/R Methodological Tool: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities, Version 2.1*. 2011, UNFCCC Annex 13 EB 60.

46. MacDicken, K.G., *A guide to monitoring carbon storage in forestry and agroforestry projects*. 1997, Winrock International

47. VCS, *VCS AFOLU Requirements Version 3.3*. 2012.

48. *The R Project for Statistical Computing*. Available from: http://www.r-project.org/.

49. VCS, *VCS Standard: VCS Version 3.3*. 2012.

50. Norris, N., *The standard errors of the geometric and harmonic means and their application to index numbers.* Annals of Mathematical Statistics, 1940. **11**: p. 445-448.

51. Akagi, S.K., et al., *Emission factors for open and domestic biomass burning for use in atmospheric models.* Atmospheric Chemistry and Physics, 2011. **11**(9): p. 4039-4072.

52. Knops, J.M.H. and D. Tilman, *Dynamics of soil carbon and nitrogen accumulation for 61 years after agricultural abandonment.* Ecology, 2000. **81**: p. 88-98.

53. Hao, X., et al., *Soil density and porosity*, in *Soils sampling and methods of analysis, second edition*, M.R. Carter, Editor. 2007, CRC Press: Boca Raton Florida USA. p. 789-799.

54. Nelson, D.W. and L.E. Sommers, *Total carbon, organic carbon, and organic matter*, in *Methods of Soil Analysis. Part 3. Chemical Methods.*, D.L. Sparks, Editor. 1996, Soils Science Society of America: Madison, Wisconsin, USA. p. 961-1010.

55. Walkley, A. and I.A. Black, *An examination of Degtjareff Method for determining soil organic matter and a proposed modification of the chromic acid titration method.* Soil Science, 1934. **37**: p. 29-37.

56. Ritchie, M.E., D. Tilman, and J.M.H. Knops, *Herbivore effects on plant and nitrogen dynamics in oak savanna.* Ecology, 1998. **79**(1): p. 165-177.

57. Norman, J.M., R. Garcia, and S.B. Verma, *Soil surface CO2 fluxes and the carbon budget of a grassland. .* Journal of Geophysical Research-Atmospheres, 1992. **97**(D17): p. 18845-18853.

58. Rajan, N., S.J. Maas, and S. Cui, *Extreme drought effects on carbon dynamics of a semiarid pasture.* Agronomy Journal, 2013. **105**(6): p. 1749-1760.

59. Sanjerehei, M.M., *Determination of an appropriate quadrat size and shape for detecting association between plant species.* Ecological Modelling, 2011. **222**(10): p. 1790-1792.

60. Seber, G.A.F., *A review of estimating animal abundance II.* International Statistical Review / Revue Internationale de Statistique, 1992. **60**: p. 129-166.

61. Tsay, P.K. and A. Chao, *Population size estimation for capture - recapture models with applications to epidemiological data.* Journal of Applied Statistics, 2001. **28**(1): p. 25-36.

62. Thomas, L., et al., *Distance 3.5. Research Unit for Wildlife Population Assessment*. 1998, University of St. Andrews: St Andrews, UK.

63. Huete, A., et al., *Overview of the radiometric and biophysical performance of the MODIS vegetation indices.* Remote Sensing of the Environment, 2002. **83**: p. 195-213.

64. Conant, R.T., K. Paustian, and E.T. Elliott, *Grassland management and conversion into grassland: Effects on soil carbon.* Ecological Applications, 2001. **11**(2): p. 343-355.

65. Derner, J.D. and G.E. Schuman, *Carbon sequestration and rangelands: A synthesis of land management and precipitation.* Journal of Soil and Water Conservation, 2007. **62**: p. 77-85.

66. Jensen, L.S., et al., *Influence of biochemical quality on C and N mineralisation from a broad variety of plant materials in soil.* Plant and Soil, 2005. **273**(1-2): p. 307-326.

67. IPCC, *Emissions: energy and transport*, in *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. 2000, IPCC National Greenhouse Gas Inventories Programme. p. 55-70.

DOCUMENT HISTORY

Version	Date	Comment
v1.0	16 July 2015	Initial version