Verified Carbon Standard

VCS Methodology

VM0041

METHODOLOGY FOR THE REDUCTION OF ENTERIC METHANE EMISSIONS FROM RUMINANTS THROUGH THE USE OF FEED INGREDIENTS

Version 2.0

21 December 2021

Sectoral Scope 15

Version 1.0 of this methodology was developed by **Mootral SA**. The lead author was **Elsa Zoupanidou;** significant contributions were provided by Maria Sünkel, Deepashree Kand, Hilde Vrancken, Matthias Miller, and Oliver Riede. Version 1.0 was approved on 22 November 2019.

Version 2.0 of this methodology was prepared by **Dr. Ermias Kebreab**, Professor and Associate Dean, College of Agricultural and Environmental Sciences, University of California, Davis with input from Verra. Additional review of Version 2.0 was provided by **Dr. Tim McAllister**, Research Scientist, Ruminant Nutrition & Microbiology at AgriFood Canada. This version expands the applicability conditions to include any type of feed additive approved for animal use and with scientifically demonstrated efficacy and increases the stringency of the procedures by which project proponents establish the enteric methane emission reduction factor. Version 2.0 was approved on 21 December 2021.

CONTENTS

1 SOURCES

The following have informed the development of this methodology:

- *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use*. Chapter 10: Emissions from livestock and manure management
- Government of Alberta (2016). *Quantification Protocol for Reducing Greenhouse Gas Emissions from Fed Cattle, v3.0*
- American Carbon Registry (2014). *Methodology for Grazing Land and Livestock Management, v1.0*

This methodology uses the latest versions of the following modules:

- *VMD0027: Estimation of Domesticated Animal Populations, v1.0*
- *VMD0028: Estimation of Emissions from Domesticated Animals, v1.0*

2 SUMMARY DESCRIPTION OF THE METHODOLOGY

Additionality and Crediting Method	
Additionality	Activity Method
Crediting Baseline	Project Method

This methodology provides procedures to estimate enteric methane (CH_4) emission reductions generated from the suppression or inhibition of methanogenesis, achieved by the introduction of a feed ingredient into ruminant diets. This methodology considers emission reductions only from enteric fermentation.

Feed ingredients applicable under this methodology reduce CH_4 emissions by directly acting on the population of methanogenic archaea in the rumen, or by suppressing CH_4 production through modification of the rumen environment, thus limiting methanogenesis.

Depending on the location in which a project is implemented and the availability of data, this methodology provides three approaches to the quantification of baseline emissions and two approaches to the quantification of project emissions. Specifically, the quantification of baseline emissions may be performed using data from either on-site direct measurements, or by applying one of two different Intergovernmental Panel on Climate Change (IPCC)-recommended methods to model emissions using country-specific or peer-reviewed biometric data. The quantification of project emissions may be performed using data from either on-site direct measurements, or by applying a published emission reduction factor derived by meta-analysis.

3 DEFINITIONS

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

Animal Group
Animals at a farm, grouped based on a homogeneous ruminant population characteristic such as animal type, weight, production phase (e.g., pregnant or lactating cow) or feeding regime

Diet
Feed ingredients or mixture of ingredients, including water, that is consumed by animals

Dry Matter Intake (DMI)
The amount of feed that an animal consumes per day, on a moisture-free basis

Emission Reduction Factor
Percentage reduction in enteric methane emissions per animal per day due to project feed ingredient or additive

Enteric Fermentation
A natural digestive process in ruminants whereby microbes catabolize and ferment feed present in the digestive tract or rumen. Enteric methane is one by-product of this process and is expelled by the animal mostly through eructation and respiration.

Enteric Methane
Methane emissions from ruminants, due to enteric fermentation of feed

Feed(s)
Edible material(s) that are consumed by an animal and contribute energy and/or nutrients to the animal's diet

Feed Ingredient
A component part or constituent of any combination or mixture making up a feed, whether it has a nutritional value in the animal's diet, including feed additives. Ingredients are of plant, animal, or aquatic origin, or other organic or inorganic substances.[1]

Gross Energy
The total caloric energy contained in feed

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[1] Definition from FAO and WHO (2004). *Codex Alimentarius Code of Practice on Good Animal Feeding CAC/RCP 54*. Available at https://www.fao.org/fao-who-codexalimentarius/thematic-areas/animal-feed/en/#c437068.

Livestock Production Operation
An agricultural setting — permanent or semi-permanent facility, grazing or non-grazing area — where domesticated animals are kept or raised either indoors or outdoors to provide traction or produce livestock commodities[2]

Methanogenesis
The anaerobic formation of methane in the rumen by microorganisms known as methanogens

Neutral Detergent Fiber (NDF)
A measure of the structural components (i.e., lignin, hemicellulose, cellulose, tannins, and cutins) within the cells of plants, which provides an estimate of fiber constituents of feedstuffs and indicates maturity. Generally, the higher the NDF, the more mature and lower quality the forage.

Reticulo-Rumen
The first large compartment of the stomach of a ruminant where fermentation, which allows for the digestion of fiber and other feeds, occurs

Ruminant
A mammal that has a different digestive system to monogastric (single stomach) animals. The primary differences are that the "stomach" of a ruminant consists of four compartments, and ruminants have the ability to regurgitate digesta and chew them, a process known as rumination. Ruminants are able to acquire nutrients from plant-based feeds by fermenting the feed in the biggest compartment, the rumen, prior to digestion. Ruminating mammals include species such as cattle, goat, sheep, deer, giraffe, and antelope.

4 APPLICABILITY CONDITIONS

This methodology applies to project activities that reduce enteric methane (CH_4) emissions through the inhibition or reduction of methanogenesis, achieved by the introduction of a feed ingredient into ruminant diets.

This methodology is applicable under the following conditions:

1) Livestock producers must feed their animals a feed ingredient that reduces enteric CH_4 emissions by direct inhibition or suppression of methanogens in the rumen or by modifying the rumen environment.
2) Only ruminant animals are included in the project.
3) The project feed ingredient must meet the following conditions:
    a) The feed ingredient must have been demonstrated to comply with all feed and food regulations in each national or subnational (including local) jurisdiction in which it

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[2] FAO (2018). *Shaping the Future of Livestock*. The 10th Global Forum for Food and Agriculture, Berlin, January 18–20, 2018. Available at http://www.fao.org/3/i8384en/I8384EN.pdf.

is consumed. Where conflict arises among regulations, the most stringent standard must apply.

b) The feed ingredient must have no negative health impacts on the animal to which it is fed. This must be shown through regulatory approval and the submission of published evidence demonstrating no negative impacts on animal health when administered in accordance with its intended conditions of use.

c) The feed ingredient must be used as per feeding instructions provided by the manufacturer. The instructions must define the critical conditions needed to secure the default level of reduction in enteric methane emissions, such as the feeding routine and dose of ingredient per kilogram of dry matter intake (DMI) by the animal.

4) Emission reductions generated using other feed ingredients and/or activities (e.g., improving animal productivity or nutritional and management strategies), where the use is not specific to the inhibition or suppression of methanogenesis, cannot be claimed through this methodology. This is to prevent overestimation of emission reductions.

5) The implementation of project activities must confirm that the herd of ruminants in a given operation is fed the feed ingredient. For this purpose, the project proponent must be able to trace the feed ingredient fed to livestock from the producer to on-farm consumption.

6) Evidence must be provided that there will be no increase in manure emissions due to the feed ingredient. This may be demonstrated by one of the following:

    a) Documentation of on-farm data showing no significant differences in manure composition due to feed ingredient consumption, or

    b) A published study that documents feed efficiency, particularly related to energy and nitrogen.

    Where there are significant increases in manure emissions, the ingredient may still be used but the project must account for CH_4 and N_2O emissions from manure using IPCC Tier 2 recommended estimation methods.

7) Baseline emissions included in this methodology consist of CH_4 production from enteric fermentation and are determined as the average activity over at least three continuous years prior to project implementation. Therefore, project activities are required to meet the following conditions:

    a) Where project areas involve livestock farms that were operating prior to the start of project activities, reliable data (e.g., feed intake in the form of energy or dry matter, nutrient composition of feed) for each animal group must be available for a minimum of two years when using baseline emissions Option 1, and three years when using baseline emissions Option 2. See Section 8.1 for further details on options for quantifying baseline emissions.

b) Where project areas involve livestock farms for which no farm records nor farming data are available, the project proponent must be able to provide evidence to substantiate the animal group (i.e., animal type, production phase) to which each new project area is allocated, according to the average group as described in national or regional statistical accounts (i.e., baseline emissions will be considered to be the average activity in the area in which the project is located).

5 PROJECT BOUNDARY

The spatial extent of the project boundary encompasses all geographic locations of ingredient production, ingredient transport, and project activity locations where feed ingredient is part of the livestock production operation.

The greenhouse gases (GHGs) included in or excluded from the project boundary are shown in Table 1

Table 1.

Table 1: GHG Sources Included In or Excluded From the Project Boundary

Source		Gas	Included?	Justification/Explanation
Baseline	Enteric Fermentation	CO_2	No	No changes in biogenic CO_2 emissions are expected as a result of the project activity.
		CH_4	Yes	CH_4 emissions from enteric fermentation prior to implementation of the project activity represent the major source of emissions in the baseline scenario.
		N_2O	No	No changes in biogenic N_2O emissions are expected as a result of the project activity.
Project	Enteric Fermentation	CO_2	No	No changes in biogenic CO_2 emissions are expected as a result of the project activity.
		CH_4	Yes	CH_4 emissions from enteric fermentation are the major source of emissions in the project scenario.
		N_2O	No	No changes in biogenic N_2O emissions are expected as a result of the project activity.
	Ingredient Production and Transport	CO_2	Yes	CO_2 emitted from ingredient production and transportation
		CH_4	Yes	CH_4 may be emitted from combustion of fossil fuels during processing of the feed ingredient.
		N_2O	No	N_2O emissions are not expected during the production process.
	Manure Decomposition	CO_2	No	No changes in biogenic CO_2 are expected as a result of the project activity.
		CH_4	Yes	Significant changes in CH_4 production via manure decomposition may occur due to project activity.
		N_2O	Yes	Significant changes in N_2O production via manure decomposition may occur due to project activity.

As indicated in Table 1, the project boundary includes CH_4 emissions from enteric fermentation. CH_4 emissions from enteric fermentation enter the atmosphere primarily via eructation and respiration. Therefore, CH_4 emissions need to be monitored from the nostrils and oral cavity only.

Ruminants release CH_4 by exhaling the gas mainly through their mouth and nostrils. Enteric CH_4 is produced mostly in the rumen (87%) and, to a smaller extent, the hindgut (13%; Murray et al., 1976). Ruminants release CH_4 by direct eructation from the rumen, by expiration of absorbed CH_4 in the blood and exhalation by the lungs, and by the hindgut in the flatus. However, 89% of methane produced in the hind gut is exhaled through the lungs (Murray et al., 1976). Exhaled gas is the combined gas released by eructation and expiration through the mouth and nostrils. As almost all of the CH_4 is released by exhalation, the project boundary does not include CH_4 emissions from flatulence. However, due to rumen physiology, in some cases the feed ingredient could have an effect on digestibility parameters, which will affect manure nutrient composition and potential CH_4 emissions during storage and field application. For this reason, if the feed ingredient is demonstrated to shift manure composition, then the project boundary must include CH_4 or N_2O emissions from decomposing manure. Manure emissions due to feed ingredients are dealt with by Applicability Condition 6 of this methodology.

6 BASELINE SCENARIO

At the project start date, the most plausible baseline scenario must be identified as the continuation of livestock operations following business as usual practices (i.e., typical feeding regime without using a feed ingredient to reduce CH_4 enteric fermentation). There are no plausible alternatives to this baseline scenario.

7 ADDITIONALITY

This methodology uses an activity method for the demonstration of additionality. Project proponents applying this methodology must determine additionality using the procedure outlined below.

Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the *VCS Methodology Requirements.*

Step 2: Positive List

The applicability conditions of this methodology represent the positive list. The project must demonstrate that it meets all of the applicability conditions, and in so doing, it is deemed to comply with the positive list.

The positive list was established using the activity penetration option (Option A in the *VCS Methodology Requirements*).

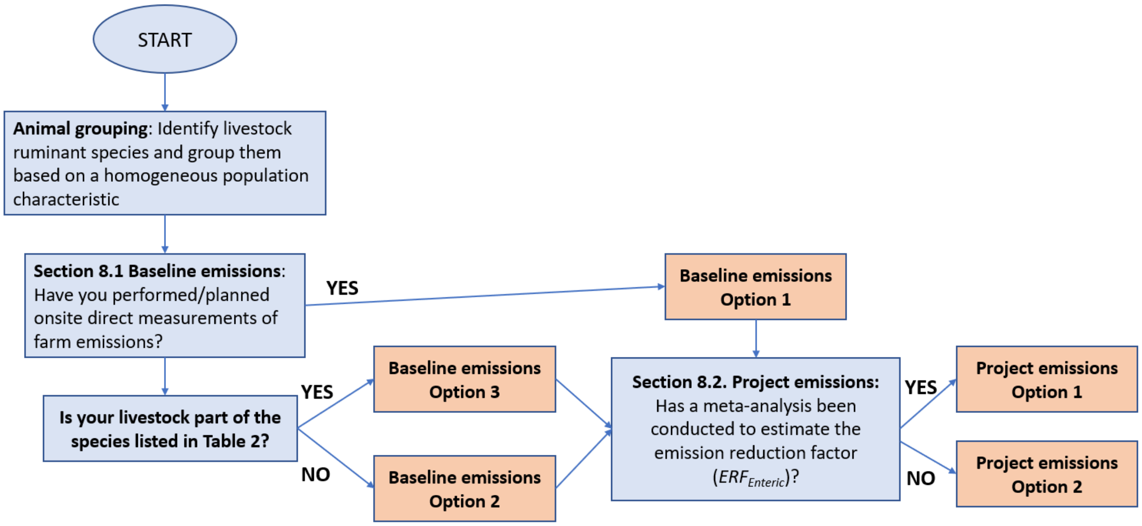
Justification for the activity method is provided in Appendix 1.

8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

This methodology proposes three approaches to the quantification of baseline emissions and two approaches to the quantification of project emissions, the applicability of each depending on data availability.

Figure 1 outlines the steps involved in determining baseline and project emissions. The steps are listed below and explained in more detail in the following sections.

Figure 1: Decision Tree for Determining CH_4 Emissions from Enteric Fermentation



8.1 Baseline Emissions

Emissions in the baseline scenario are estimated as the sum of annual emissions from enteric fermentation according to the following equation:

$$BE_{Enteric_i} = \sum_{j=1}^{n} \left[EF_{Enteric_{i,j}}\right] \times \frac{GWP}{1000} \quad (1)$$

Where:

$BE_{Enteric_i}$ = Total baseline CH_4 emissions from livestock enteric fermentation on farm *i* (tCO_2e)

Where the project activity includes multiple farms, emissions in the baseline scenario are estimated as the sum of annual emissions from each farm *i* as $\sum_{i=1}^{n}[BE_{Enteric_i}]$

$EF_{Enteric_{i,j}}$ = Enteric CH_4 emissions factor for animal group *j* during the monitoring period (kg CH_4)

GWP = Global Warming Potential of methane (dimensionless)

This methodology provides three options for determining the enteric emission factor ($EF_{Enteric_j}$). Depending on the availability of relevant project data and measurements, the project proponent must choose the most appropriate of the following options for each animal group.

$EF_{Enteric_{i,j}}$ Option 1

Option 1 calculates the enteric emission factor for each animal group by using direct enteric CH_4 measurements to estimate the CH_4 production per animal group per day (enteric emissions production factor, $EF_{Production_{i,j}}$). The enteric emissions production factor for each animal group measured by the chosen technology must be available at validation. Using Option 1, the enteric emission factor for each animal group is calculated as follows:

$$\mathbf{EF_{Enteric_{i,j}} = EF_{Production_{i,j}} \times N_{i,j} \times Days_{i,j}} \qquad (2)$$

Where:

$EF_{Enteric_{i,j}}$ = Enteric CH_4 emissions factor for animal group *j* during the monitoring period (kg CH_4)

$EF_{Production_{i,j}}$ = Mean enteric emissions production factor for animal group *j* during the baseline or monitoring period (on-site direct measurement by chosen technology, see Appendix 2) (kg CH_4 $head^{-1}$ d^{-1})

$Days_{i,j}$ = Number of days spent on farm *i* by each animal in group *j* during the monitoring period (d)

$N_{i,j}$ = Average number of head in each animal group *j* on farm *i* in the monitoring period (head)

The baseline emissions production factor ($EF_{Production}$) may be measured prior to project implementation with a sample for each animal group subsequently included in the project. Alternatively, a control group for each animal group can be used during project implementation, thus allowing baseline monitoring and project monitoring to occur simultaneously. The control group is used as a baseline measure and is identical to all other animals with the exception that it does not receive the feed ingredient. Once determined, $EF_{Production}$ remains fixed for the project crediting period. See Appendix 2 for further details regarding direct methane measurement technologies and procedures.

Farm-specific data (e.g., gross energy intake, DMI, and nutrient composition) from two consecutive years prior to project implementation must be provided during validation. These data may be given per group of animals and will be used to demonstrate that the baseline measured using Option 1 does not represent a biased event compared to prior conditions at the farm, and therefore $EF_{Production}$ reflects average activity of the project location.

$\boldsymbol{EF_{Enteric_{i,j}}}$ Option 2

Option 2 provides procedures to calculate the enteric emission factor for each animal group by applying an IPCC Tier 2 method, using the following equation:

$$EF_{Enteric_{i,j}} = \left[GEI_j \times \frac{Ym_j}{100} \times N_{i,j} \times Days_{i,j}\right] \times EC^{-1} \qquad (3)$$

Where:

$EF_{Enteric_{i,j}}$ = Enteric CH_4 emissions factor for animal group *j* during the monitoring period (kg CH_4)

GEI_j = Average gross energy intake (GEI) per animal group *j* on farm *i* (MJ head^{-1} d^{-1})

Ym_j = Conversion factor indicating the proportion of GEI converted to enteric CH_4 energy by animal group *j* (see Appendix 3); energy of CH_4 as a percentage of gross energy (dimensionless).

$Days_{i,j}$ = Number of days[3] spent on farm *i* by each animal in group *j* during the monitoring period (d)

$N_{i,j}$ = Average number of head in animal group *j* on farm *i* in the monitoring period (head)

EC = Energy content of methane (55.65 MJ kg^{-1})

Gross energy intake (GEI) is calculated by multiplying dry matter intake (DMI) by the energy density of the feedstuff, using the following equation:

$$GEI_j = \left[DMI_j \times ED\right] \qquad (4)$$

Where:

DMI_j = Average dry mass of feed consumed by animal group *j* in a given day (kg head^{-1} d^{-1})

ED = Average energy density of dry matter (MJ kg^{-1}). Default values of 19.10 MJ kg^{-1} for diets including edible oils with fat content in the range of 4 to 6% or 18.45 MJ kg^{-1} for diets including edible oils with fat content below 4% may be used.

$\boldsymbol{EF_{Enteric_{i,j}}}$ Option 3

Option 3 is only suitable for animal species listed in Appendix 4, and where the project proponent does not have the required data for Option 2. The enteric emission factor for each animal group is calculated as follows:

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[3] The number of days could be less than 365. For example, in the case of young cattle, the number of days represents the length of stay in a specific group.

$$EF_{Enteric_{i,j}} = \sum_i [EF_{i,j} \times N_{i,j} \times Days_{i,j}] \tag{5}$$

Where:

$EF_{Enteric_{i,j}}$ = Enteric CH_4 emissions factor for animal group *j* during the monitoring period (kg CH_4)

$EF_{i,j}$ = Average enteric CH_4 emissions factor for animal group *j* during the monitoring period (national or regional specific factors, or those provided in Appendix 4) (kg CH_4 head^{-1} d^{-1})

$Days$ = Number of days spent on farm *i* by each animal in group *j* during the monitoring period (d)

$N_{i,j}$ = Average number of head in animal group *j* on farm *i* in the monitoring period (head)

8.2 Project Emissions

Emissions in the project scenario are estimated as the sum of annual emissions from enteric fermentation, and from the production, transport, and application of the ingredient, according to the following equation:

$$PE_{Enteric_i} = \sum_{j=1}^{n} \left[EF_{Enteric_{i,j}}\right] \times \left[1 - ERF_{Enteric_j}\right] \times \left[\frac{GWP}{1000}\right] + EFME_i \tag{6}$$

Where:

$PE_{Enteric_i}$ = Total project enteric CH_4 emissions from livestock enteric fermentation on farm *i*, and from the production and transport of the ingredient used during the monitoring period (tCO_2e)

Where the project activity includes multiple farms, emissions in the project scenario are estimated as the sum of annual emissions from each farm *i* as $\sum_{i=1}^{n}[PE_{Enteric_i}]$

$EF_{Enteric_{i,j}}$ = Enteric CH_4 emissions factor for each animal group *j* during the monitoring period, determined using Equations (2), (3), or (4) (kg CH_4)

$ERF_{Enteric_j}$ = Enteric CH_4 emissions reduction factor (default value or determined percentage). Percentage reduction in enteric CH_4, due to feed ingredient, per animal in group *j* during the monitoring period

$EFME_i$ = Total emissions associated with manufacturing and transport of the feed ingredient for farm *i* during the monitoring period (tCO_2e)

GWP = Global Warming Potential of methane (dimensionless)

8.2.1 Enteric Methane Emissions Reduction Factor

There are two options for calculating the enteric methane emissions reduction factor.

$ERF_{Enteric_{i,j}}$ Option 1

Apply the enteric emission reduction factor (%) of the feed ingredient and calculate the emissions using Equation (5). The enteric emission reduction factor must be established through a meta-analysis of at least three peer-reviewed publications in reputable journals that are listed in the Science Citation Index Expanded. The efficacy of feed additives is influenced by dose, diet, production system, type of animal, and random variation. Therefore, a meta-analysis that considers these factors is necessary to obtain efficacy estimates within the range of the data used for the meta-analysis. The conditions of the project must not deviate greatly from the conditions under which the enteric methane emissions reduction factor is determined in the meta-analysis of published results. This applies to both the categorical parameters (e.g., animal type) and variable parameters (e.g., DMI, digestible energy, NDF, housing). In the meta-analysis, meta-regressions for *ERF* can be derived to correct for measured variables within a project that are outside the 95% confidence interval (e.g., *ERF* = *a* × DMI + *b*). Where there are significant differences in the project parameters that cannot be adjusted for in the meta-analysis, the project must use Option 2.

$ERF_{Enteric_{i,j}}$ Option 2

Determine the enteric methane emissions reduction factor for each animal group by performing direct enteric methane measurements to estimate the methane production per animal group per day while consuming the feed ingredient during the monitoring period. The project proponent can perform direct enteric methane measurements (following the guidelines in Appendix 2) during the first monitoring period, to be validated and eligible for use during the entire project crediting period, provided no significant project parameters (e.g., feeding regime, animal type, weight, production phase, conditions) have changed. The enteric emission reduction factor of the feed supplement will be quantified using Equation (7), by comparing actual project performance to enteric emission factors determined when quantifying baseline emissions (Option 1 in Section 8.1).

$$ERF_{Enteric_{i,j}} = \frac{EF_{Enteric_{i,j}} - (PE_{i,j} \times N_j \times Days_{i,j})}{EF_{Enteric_{i,j}}} \times 100 \tag{7}$$

Where:

$ERF_{Enteric_{i,j}}$ = Enteric CH_4 emissions reduction factor for animal group *j* on farm *i* (default percentage value)

$EF_{Enteric_{i,j}}$ = Enteric CH_4 emissions factor for animal group *j*, determined using Options 1, 2, or 3 in Section 8.1 (kg CH_4)

$PE_{i,j}$ = Average enteric emissions production factor for animal group *j* on farm *i* during the monitoring period (on-site direct measurement by chosen technology[4]) (kg

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[4] See Appendix 2, Table 3

CH_4 head^{-1} d^{-1})

$N_{i,j}$ = Average number of head in animal group *j* on farm *i* in the monitoring period (head)

$Days_{i,j}$ = Number of days spent on farm *i* by each animal in group *j* during the monitoring period (d)

8.2.2 GHG Emissions from Feed Ingredient Manufacturing and Transport

Emissions from the feed ingredient are estimated by including all GHG sources from manufacturing and transport. Accounting for these GHG sources is not required for a project where such emissions are shown to be *de minimis*.[5] Otherwise, these emissions must be estimated as follows:

$$EFME_i = \frac{FM_i \times EF_P}{1000} + EF_{T\,i} \tag{8}$$

Where:

$EFME_i$ = Total emissions associated with manufacturing and transport of the feed ingredient for farm *i* during the monitoring period (tCO_2e)

FM_i = Amount of feed ingredient purchased by farm *i* during the monitoring period (kg)

EF_P = Emission factor for production of feed ingredient (kg CO_2e kg^{-1})

$EF_{T\,i}$ = Emissions from transport to farm *i* of total feed ingredient consumed during the monitoring period (tCO_2e)

Project emissions from the production of the feed ingredient at the manufacturer's production facility are calculated as:

$$EF_P = (Q_{elec} \times EF_{elec}) + \left(Q_{ff\,a} \times FC_a \times EF_a\right) \tag{9}$$

Where:

Q_{elec} = Quantity of electricity from the grid used per kilogram of feed ingredient production during the monitoring period (MWh kg^{-1}); to be determined by the feed ingredient manufacturer

EF_{elec}= Emissions factor for electricity[6] (kg CO_2 MWh^{-1})

$Q_{ff\,a}$ = Quantity of fossil fuel type *a* used per kilogram of feed ingredient production during the monitoring period (volume or kg fuel kg feed ingredient^{-1}); to be determined by the feed ingredient manufacturer

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[5] The pool or source may be excluded only if it is determined to be insignificant using appropriate approved tools for significance testing (e.g., the CDM *Tool for Testing Significance of GHG Emissions in A/R CDM Project Activities, v01*. Available at http://cdm.unfccc.int/EB/031/eb31_repan16.pdf).

[6] If national or state/province values are not available, the latest approved version of the CDM *Tool to Calculate the Emission Factor for an Electricity System* may be used to determine EF_{elec}. Available at https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-07-v2.pdf/history_view.

FC_a = Energy content per unit of combusted fuel type *a* (TJ volume^{-1} or kg fuel^{-1})

EF_a = Emission factor of fuel type *a* (kg CO_2e TJ^{-1})

Project emissions from the transport of the feed ingredient to the project site are calculated as:

$$EF_{T_i} = TEF_{mi} \times D_i \times FM_i \tag{10}$$

Where:

TEF_{mi} = CO_2 emitted by transport mode *m* per kilogram of feed ingredient delivered to and consumed on farm *i* during the monitoring period (t CO_2 kg^{-1} km^{-1})

D_i = Distance travelled by transport mode *m* delivering feed ingredient consumed on farm *i* during the monitoring period (km)

FM_i = Amount of feed ingredient purchased by farm *i* during the monitoring period (kg)

8.2.3 GHG Emissions from Shifts in Manure Decomposition Due to Application of Feed Ingredient

If the feed ingredient is documented to significantly impact manure nutrient composition and related methane emissions from manure decomposition ($p \leq 0.05$), project emissions must be calculated as follows:

$$CH_4 = \sum\nolimits_{i,j,S} (N_{i,j} \times VS_{i,j} \times AWMS_{i,j,S} \times EF_{i,j,S}) \times 0.001 \tag{11}$$

Where:

CH_4 = CH_4 emissions from manure decomposition (kg CH_4 y^{-1})

$N_{i,j}$ = Average number of head in animal group *j* on farm *i* in the monitoring period (head)

$VS_{i,j}$ = Annual average excretion of volatile solids *VS* by animal group *j* on farm *i* (kg head^{-1} y^{-1}

$AWMS_{i,j,S}$= Fraction of total annual *VS* from animal group *j* that is managed in manure system *S* on farm *i* (dimensionless)

$EF_{i,j,S}$ = Emission factor for direct CH_4 emissions from manure management system S by animal group *j* on farm *i* (g CH_4 kg VS^{-1})

If the feed ingredient is documented to significantly impact manure nutrient composition and related nitrous oxide emissions from manure decomposition, project emissions must be calculated as follows:

$$N_2O = \left[\sum\nolimits_S \left[\sum\nolimits_{i,j} (N_{i,j} \times Nex_j \times AWMS_{i,j,S}) + N_{cdg(S)}\right] \times EF_{3(S)}\right] \times \frac{44}{28} \tag{12}$$

Where:

N_2O = Direct N_2O emissions from manure decomposition (kg N_2O y^{-1})

$N_{i,j}$ = Average number of head in animal group *j* on farm *i* (head)

Nex_j = Annual average N excretion per head in group *j* (kg N head^{-1} y^{-1})

$AWMS_{i,j,S}$= Fraction of total annual VS from animal group *j* managed in manure system *S* on farm *i*

$N_{cdg(S)}$ = Annual nitrogen input via co-digestate, where S is anaerobic digestion (kg N y^{-1})

$EF_{3(S)}$ = Emission factor for direct N_2O emissions from system *S* (kg N_2O-N kg N^{-1})

$\frac{44}{28}$ = Conversion of N_2O-N emissions to N_2O emissions

8.3 Leakage

In the context of this methodology, leakage could potentially consist of a change in the number of animals in the livestock operation due to impacts on livestock performance from introducing the feed ingredient, thereby necessitating changes in livestock populations in non-project operations to fulfill market demand. While feed ingredients are generally expected to have an insignificant impact on livestock performance, some studies demonstrate enhancements (e.g., Kinley et al., 2020). However, any resulting productivity improvements are not expected to impact emissions reductions and thus do not need to be accounted for. Additionally, due to the economics of livestock production, it is unlikely that the costs and risks associated with increasing or decreasing the number of animals in the operation is justified from the minimal expected changes in animal performance alone. Therefore, leakage is considered to be zero.

8.4 Net GHG Emission Reductions and Removals

Net GHG emission reductions are calculated as follows:

$$ER_{Enteric_i} = \sum_{i=1}^{n} \left[BE_{Enteric_i} - PE_{Enteric_i}\right] \tag{13}$$

Where:

$\mathrm{ER}_{\mathrm{Enteric_i}}$ = Total GHG emission reductions due to project activities during the monitoring period (tCO_2e)

$\mathrm{BE}_{\mathrm{Enteric_i}}$ = Total baseline enteric CH_4 emissions from livestock enteric fermentation on farm *i* during the monitoring period (tCO_2e)

$\mathrm{PE}_{\mathrm{Enteric_i}}$ = Total project enteric CH_4 emissions from livestock enteric fermentation on farm *i,* and from the production, transport and application of the ingredient used during the monitoring period (tCO_2e)

9 MONITORING

9.1 Data and Parameters Available at Validation

Data / Parameter	GEI_j
Data unit	MJ head^{-1} d^{-1}
Description	Average gross energy intake for a specific animal group
Equations	(3),(4)
Source of data	Records and data from livestock operator or associated partners for three continuous years of historical data prior to the initiation of the project or from national/regional statistical accounts.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Gross energy intake (GEI_j) can be calculated by multiplying dry matter intake by the energy density of the feedstuff using Equation (4). The energy density of diets is calculated based on their fat content, therefore the livestock operator or associated partners must know the fat content of the diets. Parameter to be updated with any change in feeding regime.
Purpose of Data	Calculation of baseline emissions
Comments	Calculated based on measured daily dry matter intake (DMI) and energy density

Data / Parameter	DMI_j
Data unit	kg dry matter head^{-1} d^{-1}
Description	Average dry mass of feed consumed by an animal in a given day
Equations	(4)
Source of data	Records and data from livestock operator or associated partners for three continuous years of historical data prior to the initiation of the project or from national/regional statistical accounts.
Value applied	N/A
Justification of choice of data or description of	Data must be provided by the livestock operator or associated partners for each animal group. The farm records must document the average daily dry matter intake (DMI) for each animal group in the project.

measurement methods and procedures applied	Parameter to be updated with any changes in feeding regime.
Purpose of Data	Calculation of baseline emissions
Comments	Required to calculate gross energy intake in Equation (3)

Data / Parameter	Ym_j
Data unit	dimensionless
Description	Percentage of gross energy from feed converted to methane by each animal group
Equations	(3)
Source of data	National or regional and population specific Ym values should be used where available, to better reflect population characteristics of the ruminants. Default values provided in Table 4 (Appendix 3) may be used as an alternative where regional values are not available.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Most national environmental agencies or similar government and research institutions have accurate peer-reviewed studies that provide Ym values. Therefore, these values must be preferred and used where direct applicability can be demonstrated. The IPCC default values for Ym (Table 4 in Appendix 3) are provided for different animal categories and can be used when no respective values are available from country-specific research. Table 4 provides Ym values derived from cattle with diets containing various levels of neutral detergent fibers (NDF) and digestible energy (DE). The NDF values of the feed used in the project must be available in order to use Table 4. Detailed information can be found in Appendix 3. The *IPCC Guidelines for National Greenhouse Gas Inventories* is internationally recognized, and the data provided in the guidelines are peer-reviewed. Parameters from any source (e.g., IPCC or national agencies) must apply the most conservative value of any uncertainty component. Parameters to be updated for each crediting period where new data exist.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	NDF_j
Data unit	Percentage dry matter
Description	Forage quality index
Equations	None
Source of data	Records and data from livestock operator or associated partners for three continuous years of historical data prior to the initiation of the project or from national/regional statistical accounts.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Data must be provided for each animal group by the livestock operator or associated partners. Assessment of the quality of forage is typically provided by the farmer's nutritionist when formulating rations for the animals. NDF values are used to determine Ym. Detailed information can be found in Appendix 3.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	ED
Data unit	MJ kg^{-1}
Description	Energy content of dry matter
Equations	(4)
Source of data	Default value or farm-specific data
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Farm-specific values should be used, where available. Otherwise, use the following typical energy density values: 1) 19.10 MJ kg^{-1} for diets including edible oils with fat content in the range of 4 to 6% 2) 18.45 MJ kg^{-1} for diets including edible oils with fat content below 4% Parameters to be updated for each crediting period where new data exist.
Purpose of Data	Calculation of baseline emissions

Comments	N/A

Data / Parameter	EC
Data unit	MJ kg^{-1}
Description	Energy content of methane
Equations	(3)
Source of data	Default value taken from *2006 IPCC Guidelines for National Greenhouse Gas Inventories*[7]
Value applied	55.65
Justification of choice of data or description of measurement methods and procedures applied	This is a standard property of methane (at 101.3 kPa, 15 °C). The *IPCC Guidelines for National Greenhouse Gas Inventories* is internationally recognized, and the data provided in the guidelines are peer-reviewed. Parameters to be updated for each crediting period where new data exist.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	$EF_{Enteric_{i,j}}$
Data unit	kg CH_4
Description	Enteric methane emission factor for each animal group
Equations	(1)
Source of data	Calculated using Equations (2), (3), or (5)
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	To allow flexibility for potential projects, this methodology provides different options to calculate baseline emissions. For Options 2 and 3, the first step in collecting data should be to investigate existing national statistics, national industry sources, published research, and statistics from international environmental agencies or the FAO.

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[7] Volume 4, Chapter 10, Section 10.3.2. Available at https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

	Most national environmental agencies or similar government and research institutions have accurate peer-reviewed data on emission factors and Ym for each animal group. Where no data are available, on-site farm measurements can be performed (baseline Option 1). Direct enteric methane measurements for ruminants must be conducted using state of the art technologies, which are well documented in the scientific literature and peer-reviewed publications; see examples in Table 3 in Appendix 2. Parameters from any source (e.g., IPCC, national agencies, or direct measurement) must apply the most conservative value of the uncertainty component. Parameters to be updated for each crediting period where new data exist.
Purpose of Data	Calculation of baseline emissions
Comments	Where methane emissions are directly measured, the project proponent or associated partner must demonstrate experience in methane measurement technologies (i.e., at least one team member must be a professional in the area of animal science, livestock health, or nutrition who has an M.Sc. or Ph.D. and working/research experience in the relevant discipline).

Data / Parameter	GWP
Data unit	dimensionless
Description	Global warming potential of methane over 100-year time horizon
Equations	(1),(6)
Source of data	IPCC defaults to be taken from the most recent IPCC reports
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The *IPCC Guidelines for National Greenhouse Gas Inventories* is internationally recognized and the data provided in the guidelines are peer reviewed. To be updated for each crediting period where new data exist.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

Data / Parameter	PE_j

Data unit	kg CH_4 head^{-1} d^{-1}
Description	Average project enteric CH_4 emissions calculated by direct measurements using the chosen technology on farm *i* during the monitoring period
Equations	(7)
Source of data	Measured for each animal group. Data records and study report of farm operations.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	To quantify the project enteric CH_4 emissions, an animal sample for each group is selected for direct measurement. The project proponent must describe the required sampling protocols against objective conditions. Sampling protocols must include sufficient numbers and sampling times to account for diurnal and postprandial variation in CH_4, as outlined in Appendix 2. All CH_4 measurement techniques are subject to experimental variation and random errors, which must be taken into account when reporting the final enteric CH_4 emission value. Detailed information can be found in Appendix 2. Parameter to be updated for each crediting period or where the value is no longer representative (e.g., due to changes in feeding regime, animal type, weight, production phase, geographic region, and management practices), in which case new data must be collected.
Purpose of Data	Calculation of project emissions
Comments	As direct measurements of methane emissions are required, the project proponent or associated partner must demonstrate experience in methane measurement technologies (i.e., at least one team member must be a professional in the area of animal science, livestock health, or nutrition who has an M.Sc. or Ph.D. and working/research experience in the relevant discipline).

Data / Parameter	$ERF_{Enteric_j}$
Data unit	Percentage
Description	Enteric emission reduction factor
Equations	(6),(7)
Source of data	Provided by the feed manufacturer for each animal group or calculated using Equation (7)(6). Data records and study report of farm operations.

Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	For Equation (6), the default percentage value is determined from a meta-analysis published in a reputable journal (Option 1). For Equation (7), the project proponent must provide evidence to demonstrate the percentage enteric CH_4 reduction for each animal group (Option 2). During verification, the project proponent will need to provide the scientific protocol and the results of the measurements.
Purpose of Data	Calculation of project emissions
Comments	N/A

Data / Parameter	$EF_{Production_{i,j}}$
Data unit	kg CH_4 head^{-1} d^{-1}
Description	Average project enteric CH_4 emissions calculated by direct measurements using the chosen technology on farm *i* during the monitoring period
Equations	(2)
Source of data	Measured for each animal group. Data records and study report of farm operations.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	To quantify the project enteric CH_4 production per animal, samples for each group are selected to be directly measured (Option 1). The project proponent must describe the required sampling protocols relevant to the project context. Sampling protocols must include sufficient numbers and sampling times to account for diurnal and postprandial variation in CH_4 emissions. In animal studies, the preferred scientific method is the calculation of sample size by power analysis (Charan and Kantharia, 2013). More detail is provided in Appendix 2. All CH_4 measurement techniques are subject to experimental variation and random errors, which must be taken into account when reporting the final enteric CH_4 emission value. Detailed information on reporting such errors can be found in Appendix 2. Parameter to be updated for each crediting period or where the value is no longer representative (e.g., due to changes in feeding regime, animal type, weight, production phase, geographic region, and management practices), in which case new data must be collected.
Purpose of Data	Calculation of baseline emissions Calculation of project emissions
Comments	As direct measurements of methane emissions are required, the project proponent or associated partner must demonstrate experience in

	methane measurement technologies (i.e., at least one team member must be a professional in the area of animal science, livestock health, or nutrition who has an M.Sc. or Ph.D. and working/research experience in the relevant discipline).

Data / Parameter	$EF_{i,j}$
Data unit	kg CH_4 head^{-1} d^{-1}
Description	Average enteric CH_4 emissions factor for each animal in group j during the monitoring period
Equations	(5)
Source of data	National or regional and population specific factors should be used where available, to better reflect population characteristics of the ruminants. Default values provided in Appendix 4 may be used as an alternative where regional values are not available.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	National or regional specific EF values should be used, where available, to reflect ruminant characteristics. Where using peer-reviewed literature to obtain these values, data must be drawn from reputable journals on the Science Citation Index Expanded. Where area-specific values are not available, default values provided in Appendix 4 may be used. Parameters from any source (e.g., IPCC or national agencies) must apply the most conservative value of the uncertainty component (i.e., a 50% reduction must be applied to values taken from Appendix 4), in order to account for uncertainty. Parameter to be updated for each crediting period for which new data exist.
Purpose of Data	Calculation of baseline emissions
Comments	N/A

9.2 Data and Parameters Monitored

Data / Parameter:	$N_{i,j}$
Data unit:	Number of animals (head)
Description:	Mean number of head in each animal group j consuming a feed ingredient during the monitoring period on farm i
Equations	(2),(3),(5)(4),(7),(11),(12)

Source of data:	Data records of livestock operations using the feed ingredient. Farm records.
Description of measurement methods and procedures to be applied:	Farm inventory data must be calculated as the average number of animals in each group, taking into account animal entry and exit movements from the group. This is a weighted average approach using the animal head × days factor, as demonstrated in the example below.
Frequency of monitoring/recording:	Single value depending on the number of head in each animal group using the feed ingredient. Measured by averages calculated from annual records.
QA/QC procedures to be applied:	Each farm record must list the number of animals in each group. Management and monitoring system to be established by the project proponent at the start of project. System may include data recording and verification procedures.
Purpose of data:	Calculation of baseline emissions Calculation of project emissions Calculation of emission reductions
Calculation method:	N/A
Comments:	Monitoring is established at the feed purchaser level. An appropriate and unique identification system for the purchasers, including e.g., project participant name, tax identification number, number of animals in each group, unique invoice number and date, would avoid double counting of emissions reductions claimed. At the time of reporting, baseline and project emissions must be calculated based on livestock population, climatic conditions, and other factors specific to the project and time period.

Days on feed	Number of head
1	100
2	100
3	103
Total = 3	Mean = 101

Data / Parameter:	$Days_{i,j}$
Data unit:	d
Description:	Number of days during which project activity is implemented in animal group *j* on farm *i*
Equations	(2),(3),(5),(7)
Source of data:	Data records of livestock operations using project feed ingredient

Description of measurement methods and procedures to be applied:	None
Frequency of monitoring/recording:	Once for start date of ingredient feeding and once for end date of ingredient feeding, for each animal group *j*
QA/QC procedures to be applied:	Management and quality control system to be established by the project proponent at the start of the project. System may include data recording and verification procedures. The number of days may be less than 365. For example, in the case of young cattle, the number of days represents the length of stay in specific animal group *j*.
Purpose of data:	Calculation of baseline emissions Calculation of emission reductions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	***j***
Data unit:	Animal group
Description:	Animals at each farm *i* must be grouped based on a homogeneous ruminant population characteristic
Equations	(1),(2),(3),(4),(5),(6),(7),(11),(12)
Source of data:	Data records of livestock operations using project feed ingredient
Description of measurement methods and procedures to be applied:	Ruminant population characterization: Methane emissions from ruminants vary by animal type, weight, production phase (e.g., pregnant or lactating), feed type, and seasonal conditions. Accounting for these variations in a ruminant population throughout the year is important to accurately characterize annual emissions. Project proponents must provide evidence at validation and each verification that emissions estimates are based on a homogeneous population and the herd size and individual animal characteristics remain constant for a given period. An example of the detailed characterization required for each livestock species is given in the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.[8]

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[8] Volume 4, Chapter 10, Table 10.1. Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html.

Frequency of monitoring/recording:	Once for validation and at least once per monitoring period
QA/QC procedures to be applied:	Management and quality control system to be established by the project proponent at the start of the project. System may include data recording and verification procedures.
Purpose of data:	Calculation of baseline emissions Calculation of emission reductions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	FM
Data unit:	kg month^{-1}
Description:	Amount of feed ingredient purchased by farm *i* during the monitoring period
Equations	(8),(10)
Source of data:	Data records of livestock operations purchasing project feed ingredient
Description of measurement methods and procedures to be applied:	Monitoring is established at the feed purchaser level. An appropriate and unique identification system for the purchasers is required, including e.g., client name, unique invoice number and date, feed purchase receipts, weights, and/or feed delivery records. Delivery notes and invoices must be reconciled between buyer and seller to verify the integrity of records. Sales records must be cross-checked with both buyer and seller of the feed ingredient to make sure that records are consistent.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Management and quality control system to be established by the project proponent at the start of the project. System may include data recording and verification procedures. Farm records or data managed by a third party showing both complete feed purchased monthly and manufactured complete feed delivered to each group.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	Must be measured in order to determine monthly volumes of the feed ingredient purchased

Data / Parameter:	EF_P
Data unit:	$tCO_2e\ kg^{-1}$
Description:	Emission factor for production of feed ingredient. GHG emitted per kilogram of feed ingredient. Includes all activities involved at the manufacturer's facility for the production of the feed ingredient.
Equations	(9)
Source of data:	Records and documentation provided by the feed manufacturer
Description of measurement methods and procedures to be applied:	Calculated using Equation 9
Frequency of monitoring/recording:	Monthly
QA/QC procedures to be applied:	If these values are not available, they should be developed using secondary data from databases listed in Table 1 in the FAO *Environmental Performance of Feed Additives in Livestock Supply Chains*.[9]
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	EF_{T_i}
Data unit:	tCO_2
Description:	Emission factor for transportation of feed ingredient to the feed mill or directly to farm *i* during the monitoring period. GHG emitted per kilogram of feed.
Equations	(10)
Source of data:	Records and documentation provided by the feed manufacturer

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[9] FAO (2020) *Environmental Performance of Feed Additives in Livestock Supply Chains – Guidelines for Assessment, v1*, Livestock Environmental Assessment and Performance Partnership (FAO LEAP). Available at https://doi.org/10.4060/ca9744en.

Description of measurement methods and procedures to be applied:	Calculated using Equation 10
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	The project proponent must provide evidence to demonstrate the level of emissions during the monitoring period. If these values are not available, they should be developed using Section 6.5 of the FAO *Environmental Performance of Feed Additives in Livestock Supply Chains*.[10]
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	Q_{elec}
Data unit:	MWh kg^{-1}
Description:	Quantity of electricity used by production facility and supplied by the grid per kilogram of feed ingredient produced
Equations	(9)
Source of data:	Documentation and date provided by the feed manufacturer
Description of measurement methods and procedures to be applied:	Electric utility bills provided by the manufacturer. For the production of the feed ingredient, the manufacturer must provide the electricity consumption at the specific production line used to manufacture the monthly quantity of feed ingredient. Alternatively, where product line-level data are not available, the manufacturer can use a ratio based on the percentage of the total volume produced by the facility that is represented by the feed ingredient.
Frequency of monitoring/recording:	Monthly

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[10] FAO (2020) *Environmental Performance of Feed Additives in Livestock Supply Chains – Guidelines for Assessment, v1*, Livestock Environmental Assessment and Performance Partnership (FAO LEAP). Available at https://doi.org/10.4060/ca9744en.

QA/QC procedures to be applied:	To confirm the production of feed ingredient, monthly production output data must be available to the manufacturer.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	Q_{ff}
Data unit:	Volume or kg fuel kg feed ingredient^{-1}
Description:	Quantity of fossil fuel used (L, m^3, or other, for each type of fuel) at the production facility per kilogram of feed ingredient produced
Equations	(9)
Source of data:	Report provided by the feed manufacturer
Description of measurement methods and procedures to be applied:	Fossil fuel invoices provided by the manufacturer. For production of the feed ingredient, the manufacturer must provide the quantity of fossil fuel used at the specific production line to manufacture the monthly quantity of feed ingredient. Alternatively, where product line-level data are not available, the manufacturer can use a ratio based on the percentage of the total volume produced by the facility that is represented by the feed ingredient.
Frequency of monitoring/recording:	Monthly
QA/QC procedures to be applied:	To confirm the production of the feed ingredient, monthly production output data must be available to the manufacturer.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	EF_{elec}
Data unit:	kg CO_2 MWh^{-1}

Description:	Emission factor for electricity
Equations	(9)
Source of data:	Country-specific emission factors for grid electricity from a reputable regional or national source. Otherwise, from an international organization such as the International Energy Agency (IEA).
Description of measurement methods and procedures to be applied:	Default values must be sourced from recognized, credible sources and be geographically and temporally relevant to the project context. Estimation and reference values must be obtained from the relevant national GHG inventory. The value used must be consistent with the source of generation. In the absence of local or regional data, reference values may be obtained from the most recent version of the *IPCC Guidelines for National Greenhouse Gas Inventories*.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	The latest approved version of the CDM *Tool to Calculate the Emission Factor for an Electricity System*[11] may be used to determine EF_{elec} where national or state/province data are not available.

Data / Parameter:	$\boldsymbol{FC_a}$
Data unit:	TJ volume^{-1} or kg of fuel^{-1}
Description:	Energy content per unit of fuel type *a*
Equations	(9)
Source of data:	Regional or national default values from recognized sources or IPCC reports
Description of measurement methods and procedures to be applied:	Where more than one recognized source is available, the most appropriate source must be selected, based on data quality indicators including technological appropriateness, regional specificity, and vintage of the data. These values must be based on well-documented, reliable sources (e.g., national energy balances, government publications, industry

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[11] Available at https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-07-v7.0.pdf.

	associations, World Resources Institute (WRI)/World Business Council for Sustainable Development (WBCSD) GHG Protocol). In the absence of local or regional data, reference values must be obtained from the most recent version of the *IPCC Guidelines for National Greenhouse Gas Inventories*.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$\boldsymbol{EF_a}$
Data unit:	kg GHG (CO_2, CH_4, N_2O) per L, m^3, or other
Description:	Emission factor for fuel combustion type *a*
Equations	(9)
Source of data:	Regional or national default values from recognized sources or IPCC reports
Description of measurement methods and procedures to be applied:	Where more than one recognized source is available, the most appropriate source must be selected, based on data quality indicators including technological appropriateness, regional specificity, and vintage of the data.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Default values must be sourced from recognized, credible sources and be geographically and temporally relevant to the project context. These values must be based on well-documented, reliable sources (e.g., national energy balances, government publications, industry associations, WRI/WBCSD GHG Protocol). In the absence of local or regional data, reference values must be obtained from the most recent version of the *IPCC Guidelines for National Greenhouse Gas Inventories*.
Purpose of data:	Calculation of project emissions

Calculation method:	N/A
Comments:	This parameter may be updated over the course of the crediting period (as a project description deviation) where more recent information becomes available.

Data / Parameter:	$\boldsymbol{TEF}$
Data unit:	$tCO_2\ kg^{-1}\ km^{-1}$
Description:	Emission factor values for mode of transport *m*
Equations	(10)
Source of data:	Regional or national default values from recognized sources
Description of measurement methods and procedures to be applied:	Default values must be sourced from recognized, credible sources and be geographically and temporally relevant to the project context. These values must be based on well-documented, reliable sources. The range of appropriate data must be documented, and the chosen data must be justified, using criteria that include data source (recognized and authoritative sources); geographic, temporal, and technological specificity; conservativeness (i.e., does not overestimate emission reduction); and the process by which the data have been peer-reviewed (preferred).
Frequency of monitoring/recording:	Monthly
QA/QC procedures to be applied:	Where more than one recognized source is available, the most appropriate source must be selected, based on data quality indicators including technological appropriateness, regional specificity, and vintage of the data.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$\boldsymbol{D_i}$
Data unit:	km
Description:	Total distance travelled by transport mode *m* for farm *i*

Equations	(10)
Source of data:	Data provided by the project proponent or manufacturer
Description of measurement methods and procedures to be applied:	Distance travelled by transport mode *m* delivering feed ingredient consumed during the monitoring period to the project location, farm *i*. Where the feed ingredient goes through a feedmill, then the distance to the feedmill, rather than to the farm, must be measured.
Frequency of monitoring/recording:	Monthly
QA/QC procedures to be applied:	N/A
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	Where there is a reliable, published life cycle analysis (LCA) for the production and transport of the feed ingredient, this element may not be needed.

Data / Parameter:	$\boldsymbol{VS_{i,j}}$
Data unit:	kg head^{-1} yr^{-1}
Description:	Annual average volatile solid excretion per animal group *j* on farm *i*
Equations	(11)
Source of data:	Regional or national default values from recognized sources
Description of measurement methods and procedures to be applied:	Default values must be sourced from recognized, credible sources and be geographically and temporally relevant to the project context. These values must be based on well-documented, reliable sources. The range of appropriate data must be documented, and the chosen data must be justified, using criteria that include data source (recognized and authoritative sources); geographic, temporal, and technological specificity; conservativeness (i.e., does not overestimate emission reduction); and the process by which the data have been peer-reviewed (preferred) or proposed by national recommendations for cattle nutrient requirements. If regionally specific data cannot be collected or derived, default volatile solid excretion rates from the *2019 Refinement to the*

	2006 IPCC Guidelines for National Greenhouse Gas Inventories[12] may be used.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Where more than one recognized source is available, the most appropriate source must be selected, based on data quality indicators including technological appropriateness, regional specificity, and vintage of the data.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$AWMS_{i,j,S}$
Data unit:	dimensionless
Description:	Fraction of total annual *VS* for animal group *j* on farm *i* that is managed in manure management system *S*
Equations	(11),(12)
Source of data:	Regional or national default values from recognized sources
Description of measurement methods and procedures to be applied:	Default values must be sourced from recognized, credible sources and be geographically and temporally relevant to the project context. These values must be based on well-documented, reliable sources. The range of appropriate data must be documented, and the chosen data must be justified, using criteria that include data source (recognized and authoritative sources); geographic, temporal, and technological specificity; conservativeness (i.e., does not overestimate emission reduction); and the process by which the data have been peer-reviewed (preferred). If regionally specific data cannot be collected or derived, default regionally specific $AWMS$ fractions can be found in the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.[13]
Frequency of monitoring/recording:	Annual

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[12] Volume 4, Chapter 10, Table 10.13a. Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html.

[13] Volume 4, Chapter 10, Annex 10A.2, Tables 10A.6 through 10A.9. Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html.

QA/QC procedures to be applied:	Where more than one recognized source is available, the most appropriate source must be selected, based on data quality indicators including technological appropriateness, regional specificity, and vintage of the data.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$\boldsymbol{EF_{i,j,S}}$
Data unit:	g CH_4 kg^{-1}
Description:	Emission factor for direct CH_4 emissions from manure management system *S* by animal group *j* on farm *i*
Equations	(11)
Source of data:	Regional or national default values from recognized sources
Description of measurement methods and procedures to be applied:	Default values must be sourced from recognized, credible sources and be geographically and temporally relevant to the project context. These values must be based on well-documented, reliable sources. The range of appropriate data must be documented, and the chosen data must be justified, using criteria that include data source (recognized and authoritative sources); geographic, temporal, and technological specificity; conservativeness (i.e., does not overestimate emission reduction); and the process by which the data have been peer-reviewed (preferred). If regionally specific data cannot be collected or derived, default values can be derived from the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.[14]
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Where more than one recognized source is available, the most appropriate source must be selected, based on data quality indicators including technological appropriateness, regional specificity, and vintage of the data.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A

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[14] Volume 4, Chapter 10, Table 10.14. Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html.

Comments:	N/A

Data / Parameter:	$Nex_{i,j}$
Data unit:	kg N head^{-1} yr^{-1}
Description:	Annual nitrogen excretion for animal group *j* on farm *i*
Equations	(12)
Source of data:	Regional or national default values from recognized sources
Description of measurement methods and procedures to be applied:	Default values must be sourced from recognized, credible sources and be geographically and temporally relevant to the project context. These values must be based on well-documented, reliable sources. The range of appropriate data must be documented, and the chosen data must be justified, using criteria that include data source (recognized and authoritative sources); geographic, temporal, and technological specificity; conservativeness (i.e., does not overestimate emission reductions); and the process by which the data have been peer-reviewed (preferred). If regionally specific data cannot be collected or derived, default nitrogen excretion rates from the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*[15] may be used.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Where more than one recognized source is available, the most appropriate source must be selected, based on data quality indicators including technological appropriateness, regional specificity, and vintage of the data.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

Data / Parameter:	$EF_{3(S)}$
Data unit:	kg N_2O-N kg N^{-1}

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[15] Volume 4, Chapter 10, Table 10.19. Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html.

Description:	Emission factor for direct N_2O emissions from manure management system S
Equations	(12)
Source of data:	Regional or national default values from recognized sources
Description of measurement methods and procedures to be applied:	Default values must be sourced from recognized, credible sources and be geographically and temporally relevant to the project context. These values must be based on well-documented, reliable sources. The range of appropriate data must be documented, and the chosen data must be justified, using criteria that include data source (recognized and authoritative sources); geographic, temporal, and technological specificity; conservativeness (i.e., does not overestimate emission reduction); and the process by which the data have been peer-reviewed (preferred). If regionally specific data cannot be collected or derived, default N_2O emission factors from the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*[16] may be used.
Frequency of monitoring/recording:	Annual
QA/QC procedures to be applied:	Where more than one recognized source is available, the most appropriate source must be selected, based on data quality indicators including technological appropriateness, regional specificity, and vintage of the data.
Purpose of data:	Calculation of project emissions
Calculation method:	N/A
Comments:	N/A

9.3 Description of the Monitoring Plan

The project proponent must establish, maintain, and apply a monitoring plan and GHG information system that includes criteria and procedures for obtaining, recording, compiling, and analyzing data, parameters, and other information important for quantifying and reporting GHG emissions. Where measurement and monitoring equipment is used, the project proponent must ensure that the equipment is calibrated according to current good practice (e.g., relevant industry standards).

The project proponent must be able to demonstrate that the ruminants for which it is claiming emission reductions have been fed with the appropriate quantity of feed ingredient. In order to

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[16] Volume 4, Chapter 10, Table 10.21. Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html.

do so, project proponents must provide detailed feeding records as per manufacturer instructions (Applicability Condition 3c) for each farm as well as proof of purchase of an appropriate quantity of the feed ingredient. Proof of purchase may be provided through delivery receipts and invoices, which must contain batch information or other identification information, that can trace the feed ingredient back to the manufacturer.

All necessary documents must be collected and centrally stored by the project proponent and be available for verification at any time. The data subject to monitoring and required for verification must be archived and stored in electronic format by the project proponent for at least two years after initial verification.

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APPENDIX 1: ACTIVITY METHOD

The initial assessment of activity penetration indicates that there is not enough activity in any country that would put such penetration above the 5% threshold called for in the VCS Program rules. It is known that no country has an activity penetration rate higher than 5% at this time due to limits in the availability of unique technologies.

Per the VCS rules, Verra will reassess whether the activity penetration levels remain within the permitted threshold within three years of the initial approval of the methodology. At that time, Verra will base its assessment on national boundaries, focusing on countries where feed ingredients that reduce methanogenesis have been used. Also, and in the spirit of conservativeness, where sub-national regulations or policies may impact the likelihood of the project activity being implemented, Verra may use such boundaries as the basis of the reassessment of the activity penetration rate.

Positive List

This project activity in particular, and CH_4 enteric fermentation reduction in general, is a relatively new field with few, if any, fully commercial technologies. Thus, the methodology uses an activity method for demonstrating additionality, with this technology (the feed ingredient) as the basis for a positive list. This approach stipulates that the total number of ruminants fed with a feed ingredient inhibiting methanogenesis does not amount to 5% or more of the total number of ruminants in agricultural settings worldwide. Five percent is the activity penetration threshold set by the *VCS Methodology Requirements v4.0* and is determined by taking the observed activity (OA) divided by the maximum adoption potential (MAP). Where the result of this calculation is less than 5%, the project activity may be considered additional.

Activity penetration is given as:

$$AP_y = \frac{OA_y}{MAP_y} \times 100$$

Where:

AP_y = Activity penetration of the project activity in year *y* (percent)

OA_y = Observed adoption of the project activity in year *y*

MAP_y = Maximum adoption potential of the project activity in year *y*

Maximum Adoption Potential of the Project Activity in Year *y*

The *VCS Methodology Requirements v4.0* defines MAP as "the total adoption of a project activity that could currently be achieved given current resource availability, technological capability, level of service, implementation potential, total demand, market access and other relevant factors within the methodology's applicable geographically defined market." In this case, given the early stage of development of feed ingredients for reducing enteric methane emissions, it is difficult to determine whether there are any resource (or other) constraints that would limit adoption of this technology.

However, for the purposes of this methodology, the maximum adoption potential of this activity may be limited to ruminants that have been reared for the production of meat and dairy products worldwide. The reason for this selection is due to market access and implementation constraints (e.g., necessary infrastructure for transporting the feed ingredient to the farm, and appropriate facilities to administer the feed ingredient to the animal on a regular basis).

In 2019, the global ruminant livestock population was roughly 4.44 billion,[17] of which approximately 2.67 billion represents the total number of livestock animals used for meat and dairy products. Table 2 lists the number of ruminant livestock animals used for dairy and meat products.

Table 2: Total number of ruminant livestock animals used for dairy and meat products in 2019 (FAOSTAT, 2021)

Type of animal	Number of animals
Dairy buffalo	75,743,127
Dairy cattle	270,985,026
Dairy sheep and goat	508,839,234
Buffalo for meat production	32,154,715
Cattle for meat production	365,076,041
Sheep and goat for meat production	1,422,142,701
TOTAL	2,674,940,844

According to the UN FAO,[18] grazing animals supply about 30% of the world's production of beef and about 23% of the world's production of lamb and mutton. For this analysis, it is conservatively assumed that 30% of buffalo and goat meat production also come from grazing animals. In grazing conditions, logistical factors limit the ability to regularly administer feed ingredients (i.e., the dispersed nature of livestock for long time periods). In theory, feed ingredients could be administered to some percentage of grazing animals (e.g., through animal mineral blocks). Nonetheless, for this analysis, grazing animals can be conservatively excluded from the calculation of MAP. On the contrary, dairy animals are not excluded as they can have daily access to feed in the milking parlor. Therefore, for the purposes of this methodology, the maximum adoption potential of this activity is limited to MAP_y = 2,182,878,026.

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[17] For the purpose of this analysis, the ruminant sector comprises cattle, sheep, goat, and buffalo. The global ruminant population in 2019 was estimated to be 4,438,416,429 (data retrieved in 2021, from http://www.fao.org/faostat/en/#data).

[18] Bruinsma, J. (Ed.) (2003). *World Agriculture: Towards 2015/2030 – An FAO perspective*. Earthscan. http://www.fao.org/3/y4252e/y4252e.pdf

Observed Adoption of the Project Activity in Year y

Few dietary strategies have been proposed to lower methane production in ruminants (Boadi et al., 2004; Knapp et al., 2014). Most are not commercially available and/or have no impact on enteric fermentation. Currently, only a few products have been observed in the market. Namely, linseed and alfalfa products containing high levels of omega-3 fatty acids can reduce the level of saturated fatty acids; the elevation of dietary fat levels in ruminant diets may be a suitable way of lowering methane production. In 2008, linseed and alfalfa were fed to approximately 50,000 cows.[19] By 2018, a different product consisting of a blend of essential oils that claims to reduce methane production by cattle had reached approximately one million cattle.[20] Neither of these examples report on the reduction in enteric emissions via a reduction in methanogenesis. However, for the purposes of this demonstration of additionality, it is assumed that the project activities are the same (i.e., feed ingredients reducing enteric emissions via reduction in methanogensis). To be conservative, it is assumed that the published reports were only capturing half of all enteric emission reduction activities, which results in an estimated activity of 2.1 million ruminants.

Therefore:

$$AP_y = OA_y \div MAP_y \times 100$$

$$AP_y = 2{,}100{,}000 \div 2{,}182{,}000{,}000 \times 100$$

$$AP_y = 0.096\%$$

$$AP_y < 5\%$$

Given the current ruminant population and the commercially available feed ingredients, in particular those which have a significant effect on inhibiting or suppressing enteric methane emissions from methanogens in the rumen, the activity penetration level of the project activity covered by this methodology is below the 5% threshold, and the project activity may be deemed additional.

Where the project activity has been commercially available in any area of the applicable geographic scope for less than three years (i.e., it uses a new technology or measure), it must be demonstrated that the project activity faces barriers to its uptake, per the VCS rules. This proposed project activity is deemed to face technological barriers that prevent its implementation for the following reasons:

1) The project activity requires extra effort from farmers to administer the feed ingredient as per feeding instructions provided by the manufacturer. In some cases, this might require appropriately trained farmers to secure the default level of reduction in enteric methane emissions, such as through managing feeding routines and dosage, and to maintain the technology in a way that does not lead to an unacceptably high risk of equipment disrepair and malfunctioning or other underperformance.

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[19] FeedInfo News Service (2010). Interview: France's Valorex extracts value from overlooked grains. March 8, 2010. http://www.pinallet.com/data/FEEEDINFO%20Interviews%20VALOREX%20CEO.pdf

[20] Munda, A. (2018). Swiss company develops new cow feed to cause fewer farts. *The Green Optimistic*, October 6, 2018. https://www.greenoptimistic.com/swiss-company-develops-new-cow-feed-fewer-farts-20181006/#.XF

2) Project activity implementation will require the purchase of feed ingredient, which is an addition to variable costs for existing farmers. Farmers make multiple decisions in the agricultural cycle about the adoption of products and practices. According to Loevinsohn et al. (2013), farmers' decisions about whether and how to adopt new technology are often the result of a comparison of the uncertain benefits of the new invention with the uncertain costs of adopting it. For adoption to occur, farmers need to know that a technology exists, believe that it will improve productivity, and understand how to use it effectively. Given the early stage of development of feed ingredients for reducing enteric methane emissions, and uncertainties with regard to their impacts on growth performance, the lack of willingness of farmers to adopt and continue the activity may increase the risk of technological failure.

3) The majority of feed ingredients applicable under this methodology are natural products that occur during a certain time of year (seasonal crops). Therefore, working capital can fluctuate widely, which can lead to an unacceptably high risk to technology availability. Since this methodology is based on plants or algae, project activity implementation will require management of seasonal effects on working capital. During the seasonal peak, a feed ingredient manufacturer may require higher net investment in short-term (current) assets.

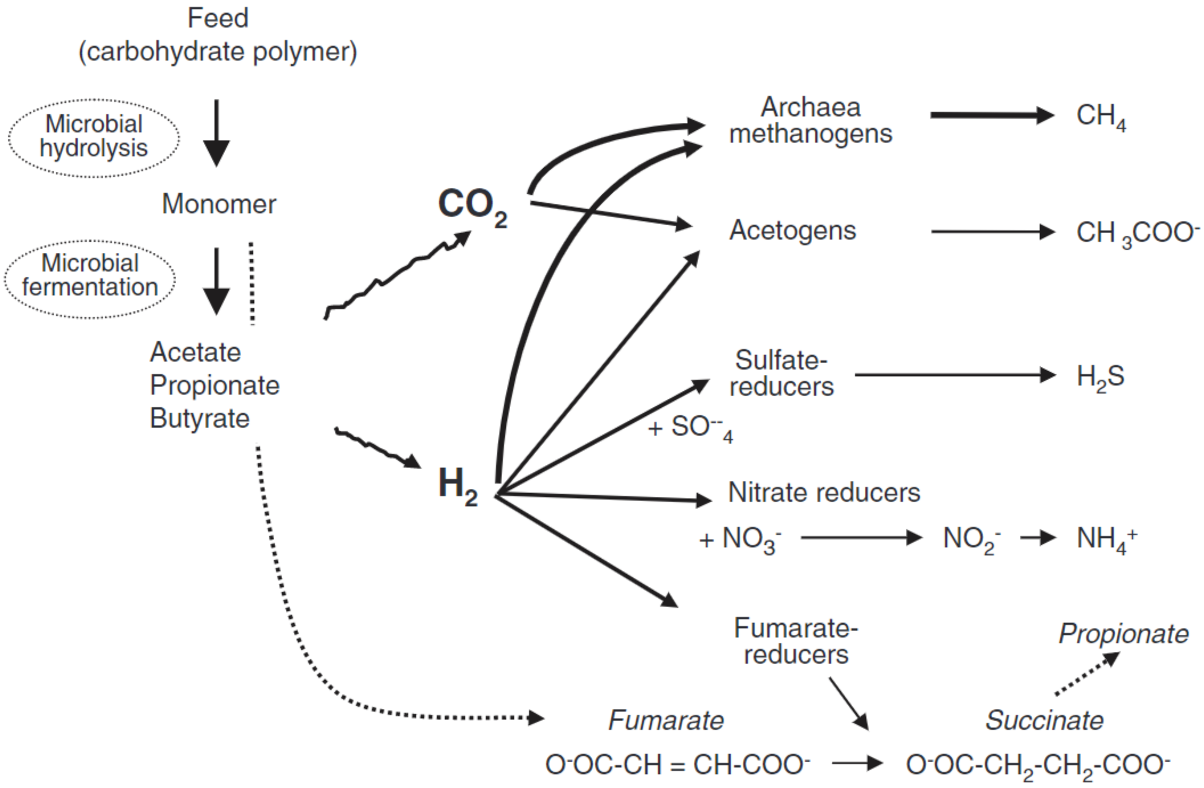
APPENDIX 2: BACKGROUND INFORMATION ON PROJECT ACTIVITY

Enteric fermentation is the second largest source of global emissions from livestock supply chains, contributing approximately 40% of total emissions. Cattle emit 77% of all enteric methane (Gerber et al., 2013). Ruminants, in particular, release methane as a result of the fermentation of feed material in the rumen. These are enteric emissions from ruminants and are significant contributors to greenhouse gas emissions.

Research on various feed management activities has already been conducted to assess their ability to reduce methane production (Eger et al., 2018). Enteric methane is produced from microbial fermentation of feed (Hobson et al., 1981; Whitford et al., 2001). Primary anaerobic microbiomes degrade organic matter into volatile fatty acids. In this process, hydrogen gas and carbon dioxide are produced as by-products. Methanogens metabolize hydrogen and carbon dioxide into methane (Hegarty, 1999; Moss et al., 2000). Figure 2 provides an illustration of the microbial fermentation of feed polysaccharides and H_2 reduction pathways to CH_4 in the rumen.

Reducing enteric fermentation enables livestock producers to reduce the environmental impact of meat and dairy products and provide consumers with sustainable climate-friendly products with a quantified carbon footprint reduction. The production of methane in the rumen can represent a loss of energy of up to 12% (Johnson and Johnson, 1995). Therefore, potential production increases and energy efficiencies achieved through use of the feed ingredient could be complementary outcomes of reducing enteric methanogenesis.

Figure 2: Schematic of microbial fermentation of feed polysaccharides and H_2 reduction pathways to CH_4 in the rumen (Morgavi et al., 2010)



Direct Enteric Methane Measurements

Direct enteric methane measurements for ruminants may be conducted using state of the art methods, which are well documented in the scientific literature. This includes respiration chambers, which have been an established and widely used technique since 1958. However, some operations require measurements of CH_4 emissions of a larger number of animals. Short-term measurement techniques, such as automated head chambers (e.g., the GreenFeed system) (Hammond et al., 2016), can be used to meet this objective with spot measurement of gas concentrations in samples of exhaled air at certain time points. A single spot measurement is not sufficient; repeated spot measurements are required and can be taken whilst the animals are feeding or standing. There are diverse technologies being used worldwide for quantifying enteric methane emission. However, there is no integrated protocol covering all aspects, including data collection, data extraction, data handling, and estimating methane volume from the measured concentration. Experience in animal studies is required to develop a protocol that will generate accurate results.

In case the manufacturer of the feed ingredient cannot provide sufficient documentation through peer-reviewed publications to support calculation of emission reduction factors, the project proponent must perform direct enteric methane measurements. The baseline emission factors may still be set using

Options 2 or 3 as described in Section 8.1. Overall, the chosen measurement technology and the measuring procedures must meet the following conditions:

1) The technology must be well documented in the scientific literature in peer-reviewed publications.
2) The technology enables measurements for animals that can be applied under conditions relevant to project livestock production.
3) The measurement error of the technology and sampling error must be reported under the project conditions.
4) The project proponent or associated partner must demonstrate technical skills and experience in operating direct enteric methane measurements to generate accurate results.
5) The recommended measurement protocol must determine: *i*) optimal sample size, and *ii*) recording duration. Calculation of sample size is an important component of design in animal studies. Using too few animals may lead to a failure to detect significant differences that may exist in the population. The following formula can be used to calculate sample size for comparison between baseline and project groups (Charan and Kantharia, 2013):

   $$\text{Sample size} = 2\ SD^2\ (1.96 + 0.842)^2\ d^{-2}$$

   Where SD is the standard deviation from previous studies or pilot studies to measure the variability between animals and *d* is the minimum expected difference between the observed means of two groups (baseline versus project). Detailed information on optimal sample size calculation is given by Charan and Kantharia (2013).
6) A minimum trial duration of eight weeks is required. The recording duration depends on the measurement method used. For respiration chambers, three measurement periods (lasting three days each) over three weeks is considered adequate based on the literature. Methane emissions measured using the GreenFeed system must be measured every two to three weeks for at least three measurement periods. During each measurement period, gas emission data should be collected over three days as follows: starting at 0900, 1500, and 2100 h (sampling day 1), 0300, 1200, and 1700 h (sampling day 2), and 0000 and 0500 h (sampling day 3) (Hristov et al., 2015). Multiple visits to the measurement device by all individual animals within a group must be confirmed.
7) The project proponent must estimate the measurement uncertainty and apply confidence deductions to reduce bias and uncertainties as far as is practical. Methods used for estimating uncertainty must be based on recognized statistical approaches such as those described in the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (Gibbs et al., 2000). Confidence deductions must be applied using conservative factors such as those specified in the CDM Meth Panel *Guidance on Addressing Uncertainty in the Estimation of Emissions Reductions for CDM Project Activities*.[21]

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[21] CDM Meth Panel (2008). Thirty-second meeting report, Annex 14. https://cdm.unfccc.int/Panels/meth/meeting/mp_08.html#032

Table 3 provides a description of three different technologies for direct measurement of enteric methane emissions and, therefore, calculation of emission reductions, following a specific scientific protocol. These three technologies are used for demonstration purposes and are not restrictive, as improvements to technologies could allow more accurate measurements in the future.

Table 3: Technologies for measuring enteric methane emissions

Type of measurement method/technology	Description
Respiration chamber	Respiration chambers are used to measure CH_4 of individual animals under research conditions. The principle of the respiration chamber is to collect exhaled CH_4 emissions from the animal from all sources of enteric fermentation (mouth, nostrils, and rectum) and measure the CH_4 concentration. The cow must be in the chamber for up to four days. All open-circuit chambers are characterized by an air inlet and exhaust fans. Each chamber is fitted with internal ventilation fans for efficient mixing of expired and incoming gases. The chamber is equipped with sensors for measuring relative humidity, temperature, barometric pressure, and gases (CH_4, H_2, O_2, H_2S).
Automated head chamber – Infra-red method for methane measurements (e.g., GreenFeed – Large Animals)	Short-term CH_4 emissions can be measured by automated head chambers. One such device is the GreenFeed (GF) system (C-Lock Inc., Rapid City, South Dakota, USA). The GF system is a static short-term measurement device that measures emissions of CH_4 (and other gases, including CO_2) from individual ruminants by integrating measurements of airflow, gas concentration, and detection of head position during each animal's visit to the unit (Zimmerman and Zimmerman, 2012).
SF_6 tracer gas technique	The SF_6 technique utilizes SF_6 as a tracer gas, which is continuously released from a permeation tube inserted in the rumen of the animal, collection of a sample of the exhaled gases, and analysis of the gas for the SF_6:CH_4 ratio (Hristov et al., 2015). SF_6 is a powerful greenhouse gas, and thus should be used responsibly, with all reasonable efforts to minimize SF_6 losses and waste. Accumulation of SF_6 within confined feeding spaces can also reduce the accuracy of the technique.

APPENDIX 3: PERCENTAGE OF GROSS ENERGY IN FEED CONVERTED TO METHANE (Ym) FOR A SPECIFIC ANIMAL GROUP

The Ym value is defined as the percentage of gross energy intake by a ruminant that is converted to methane in the rumen. As described in Section 9.1 for Ym, national environmental agencies or similar government and research institutions may have accurate peer-reviewed studies that provide Ym values.

In the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, default values for CH_4 conversion rates are provided for different animal categories that may be used when no respective values are available from country-specific research (Table 4). These estimates are based on the general feed characteristics and production practices found in either developed or developing countries and take into account both digestible energy (DE) and neutral detergent fiber (NDF). When the quality of the feed is good, the lower bounds must be used (i.e., high digestibility and energy value). Higher bounds are more appropriate when poorer quality feed is available. NDF is often considered a good determinant of quality. It measures total cell wall content of plant matter and indicates maturity; the higher the value, the more mature and generally the lower the quality the forage.

Table 4: Livestock CH_4 Conversion Factors

Livestock category	Feed quality		Ym[22] (%)
	Digestible energy (%)	Neutral detergent fiber (% DMI)	
Dairy cows and buffalo	≥70	≥35	6.0
	63–70	>37	6.3
	≤62	>38	6.5
Nondairy and multi-purpose cattle and buffalo	≤62		7.0
	62–71		6.3
	≥72		4.0
	>75		3.0

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[22] Unless noted otherwise, uncertainty values are ±20% based on published standard deviations drawn from Niu et al. (2018).

Sheep	N/A		6.7 ± 0.9
Goats	N/A		5.5 ± 1.0

Source: IPCC (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10, Tables 10.12 and 10.13.

APPENDIX 4: ENTERIC FERMENTATION EMISSION FACTORS FOR LIVESTOCK

Table 5 shows the enteric fermentation emission factors for cattle and buffalo. A range of emission factors is shown based on typical regional conditions and type of productivity system. Table 6 shows enteric fermentation emission factors for sheep and goats by production system type. These values are derived from the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Table 5: Tier 1 and Tier 1a Enteric Fermentation Emission Factors for Cattle and Buffalo (kg CH_4 head^{-1} y^{-1})

Region	Livestock	Emission Factor
North America	Dairy cattle	138
	Other cattle	64
Western Europe	Dairy cattle	126
	Other cattle	52
	Buffalo	78
Eastern Europe	Dairy cattle	93
	Other cattle	58
	Buffalo	68
Oceania	Dairy cattle	93
	Other cattle	63
Latin America	Dairy cattle	87
	High productivity systems	103
	Low productivity systems	78
	Other cattle	56
	High productivity systems	55
	Low productivity systems	58

	Buffalo	68
Asia	Dairy cattle	78
	High productivity systems	96
	Low productivity systems	71
	Other cattle	54
	High productivity systems	43
	Low productivity systems	56
	Buffalo	76
Africa	Dairy cattle	76
	High productivity systems	86
	Low productivity systems	66
	Other cattle	52
	High productivity systems	60
	Low productivity systems	48
Middle East	Dairy cattle	76
	High productivity systems	94
	Low productivity systems	62
	Other cattle	60
	High productivity systems	61
	Low productivity systems	55
Indian Subcontinent	Dairy cattle	73
	High productivity systems	70
	Low productivity systems	74
	Other cattle	46
	High productivity systems	41
	Low productivity systems	47

	Buffalo	85

Note: All estimates have an uncertainty of ±20%. Source: IPCC (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10, Table 10.11.

Table 6: Tier 1 Enteric Fermentation Emission Factors for Sheep and Goats (kg CH_4 head^{-1} y^{-1})

Livestock	Emission Factor	
	High Productivity System	Low Productivity System
Sheep	9	5
Goat	9	5

Note: All estimates have an uncertainty of ±30-50%. Source: IPCC (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10, Table 10.10.