Verified Carbon Standard

Draft VCS Methodology

VM0041

REDUCTION OF ENTERIC METHANE EMISSIONS FROM RUMINANTS THROUGH USE OF FEED INGREDIENTS

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Sectoral Scope 15: Livestock and Manure Management

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1 SUMMARY DESCRIPTION

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

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

Additionality is assessed through a combined approach that uses an activity method or project method depending on the activity penetration rate (Section 7 and Appendix 1).

There are three approaches to quantifying baseline emissions and two approaches to quantifying project emissions, dependent on the location in which a project is implemented and the availability of data. Baseline emissions may be quantified either using data from on-site direct measurements or by applying one of two Intergovernmental Panel on Climate Change (IPCC)-recommended methods to model emissions using country-specific or peer-reviewed biometric data. Project emissions may be quantified either using data from on-site direct measurements or by applying a published emission reduction factor derived by meta-analysis.

2 SOURCES

This methodology uses the most recent version of the following Verified Carbon Standard (VCS) tool:

- *VT0008 Additionality Assessment*

3 DEFINITIONS

In addition to the definitions set out in the most recent version of 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
Edible material that is consumed by an animal and contributes 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 or not it has 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] that reduce enteric methane (CH_4) emissions through inhibiting or reducing methanogenesis.

Feed regime
A systematic plan of total energy intake and nutrient content of a diet that determines the total dry matter intake (DMI) and energy density (ED) per animal in a day

Gross energy
Total caloric energy contained in feed

Herd structure

The number of animals and the animal groups in each farm

[1] Adapted from FAO and WHO. 2004. *Codex Alimentarius Code of Practice on Good Animal Feeding CAC/RCP 54*. Available at https://www.fao.org/feed-safety/resources/resources-details/en/c/1054052/

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 plant cells, 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.

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 can regurgitate digesta and chew them, a process known as rumination. Ruminants can 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 inhibiting or reducing methanogenesis, achieved by the introduction of a feed ingredient into ruminant diets. The methodology is globally applicable.

This methodology is applicable under the following conditions:

1) Livestock producers 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:
    a) has regulatory approval by government or regulatory agencies for use with livestock systems.
    b) is authorized for animal production use and officially registered by the national or subnational (including local) jurisdiction in which it is consumed. The official

[2] Adapted from 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

registration must be publicly available in an official register. Where conflict arises among regulations, the most stringent standard applies.

c) has 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.

d) is used as per the manufacturer’s feeding instructions. 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) Where project areas involve livestock farms that were operating prior to the start of project activities, reliable data for each animal group[3] are available for at least two years when using baseline emissions Option 1 and three years when using baseline emissions Option 2 (see Section 8.1).

5) Where project areas involve livestock farms for which no farm records nor farming data are available, evidence is available 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.

This methodology is not applicable under the following conditions:

6) Methane emission reductions are generated using other feed ingredients or activities whose use is not specific to the inhibition or suppression of methanogenesis (e.g., improving animal productivity or nutritional and management strategies).

7) Use of the feed ingredient results in an increase in methane and nitrous oxide emissions from manure decomposition, unless there is no alternative feed ingredient approved for use in the project area.

8) The project activity changes herd structure or feed regime, unless these changes would have also occurred in the baseline scenario.[4]

9) The project activity includes planned changes in antibiotic use (type or dosage).

Note – Unexpected or unplanned changes to antibiotic use to address animal health concerns are permitted where appropriately justified and where direct measurements of

[3] For example, feed intake in the form of energy or dry matter, nutrient composition of feed

[4] Evidence to demonstrate herd structure changes may include market analyses and reports from relevant agencies (e.g., national or regional livestock advisory service providers), farm data monitoring records, or other evidence that shows reduced market demand, shifts in consumer preferences, or other drivers of change. Evidence to demonstrate feed regime changes may include supply change shifts of the new feed, along with monitoring farm data records, regional/local weather data, or reports from relevant agencies documenting environmental stressors such as droughts, floods, or other local or regional impacts affecting feed availability and composition, and laboratory analyses (i.e., nutrient concentration and digestibility).

enteric emissions (Option 1) or peer-reviewed literature demonstrate that the new use of antibiotics does not lead to an increase in enteric emissions.

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. GHG sources and sinks accounted for as baseline, project, and leakage emissions

Source		Type	Gas	Included?	Justification/Explanation
Baseline	Enteric fermentation	Source	CO_2	No	No changes in biogenic CO_2 emissions are expected as a result of the project activity.
		Source	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.
		Source	N_2O	No	No changes in biogenic N_2O emissions are expected as a result of the project activity.
	Manure decomposition	Source	CO_2	No	No changes in biogenic CO_2 are expected as a result of the project activity.
		Source	CH_4	Yes/No	Required where significant changes in CH_4 production via manure decomposition may occur due to the project activity.
		Source	N_2O	Yes	Significant changes in N_2O production via manure decomposition may occur due to project activity.
Project	Enteric fermentation	Source	CO_2	No	No changes in biogenic CO_2 emissions are expected as a result of the project activity.
		Source	CH_4	Yes	CH_4 emissions from enteric fermentation are the major source of emissions in the project scenario.
		Source	N_2O	No	No changes in biogenic N_2O emissions are expected as a result of the project activity.
		Source	CO_2	Yes	CO_2 emitted from ingredient production and transportation

	Ingredient production and transport	Source	CH_4	Yes	CH_4 may be emitted from combustion of fossil fuels during processing of the feed ingredient.
		Source	N_2O	Yes	N_2O may be emitted during the production of nitrate-based feed ingredients.
	Manure decomposition	Source	CO_2	No	No changes in biogenic CO_2 are expected as a result of the project activity.
		Source	CH_4	Yes/No	Required where significant changes in CH_4 production via manure decomposition may occur due to the project activity.
		Source	N_2O	Yes	Significant changes in N_2O production via manure decomposition may occur due to the project activity.
Leakage	Increased animal population	Source	CO_2	No	While feed ingredient may improve performance, the costs and risks associated with increasing or decreasing the number of animals in an operation make it unlikely that any productivity improvement would lead to decisions to alter animal populations and therefore increase GHG emissions.
		Source	CH_4		
		Source	N_2O		

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

As almost all CH_4 is released by exhalation,[5] the project boundary does not include CH_4 emissions from flatulence. However, due to rumen physiology, in some cases the feed ingredient could affect digestibility parameters, which will impact manure nutrient composition and potential CH_4 emissions during storage and field application. Project proponents should demonstrate no significant differences in manure composition due to feed ingredient consumption through documentation of on-farm data or a published study that documents feed efficiency, particularly related to energy and nitrogen content.

Where the feed ingredient shifts manure composition and an expert attests that there is no alternative feed ingredient approved for use in the project area, the project boundary must include CH_4 or N_2O emissions from decomposing manure using IPCC Tier 2 recommended estimation methods.

[5] Ruminants release CH_4 by exhaling it 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.

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., historical three-year 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 and a project method for the demonstration of additionality.

7.1 Regulatory Surplus

The project proponent must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the most recent version of the *VCS Standard* and *VCS Methodology Requirements.*

Where the project proponent demonstrates regulatory surplus for the project activity, proceed to Section 7.2 (positive list) or Section 7.3 (barrier analysis and/or investment analysis). Otherwise, the project activity is not additional.

7.2 Positive List

Where the project is located in regions with an activity penetration below 5% (Latin America, India, South Asia, Sub-Saharan Africa; see Table 2 in Appendix 1), the project activity is deemed additional and Sections 7.3 and 7.4 do not apply. Where the project is located in any other region, proceed to Section 7.3.

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.

7.3 Barrier Analysis and Investment Analysis

The project proponent must follow the procedures and requirements of the most recent version of *VT0008 Additionality Assessment* to conduct either a barrier analysis (Step 2 of *VT0008*) or an investment analysis (Step 3 of *VT0008*). Project proponents may choose to apply both analyses to further strengthen the additionality demonstration.

Where the project proponent demonstrates that all conditions of either the barrier analysis or the investment analysis per *VT0008* are met, proceed to Section 7.4. Otherwise, the project activity is not additional.

7.4 Common Practice Analysis

The project proponent must demonstrate that the project activity is not common practice as per Step 4c (Common Practice Analysis for Measures Not Listed in Step 4a) of the most recent version of *VT0008*.

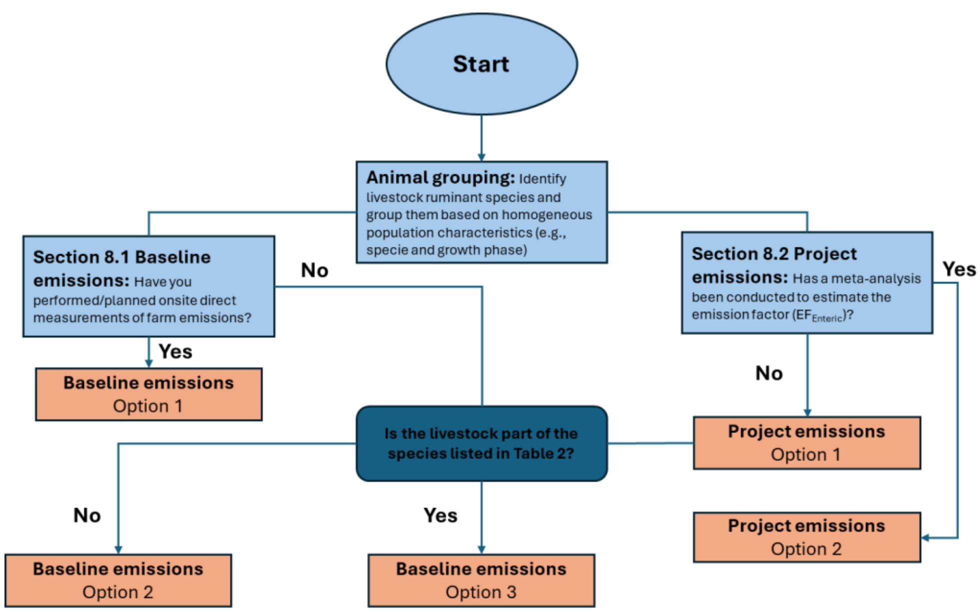
Where the project activity is not common practice, the proposed project activity is additional. Otherwise, the project activity is not additional and is not eligible for crediting.

8 QUANTIFICATION OF REDUCTIONS AND REMOVALS

There are 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:

$$BE_{Enteric_i} = \sum_j EF_{Enteric_{i,j}} \times \frac{GWP_{CH4}}{1000} \quad (1)$$

Where:

$BE_{Enteric_i}$	=	Total baseline CH_4 emissions from livestock enteric fermentation on farm *i* during the monitoring period (t CO_2e)
$EF_{Enteric_{i,j}}$	=	Enteric CH_4 emissions for animal group *j* from farm *i* during the monitoring period (kg CH_4)
GWP_{CH4}	=	Global warming potential of methane (dimensionless)

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 $\sum_{i=1}^{n} BE_{Enteric_i}$.

There are three options for determining enteric emissions ($EF_{Enteric_{i,j}}$). 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 enteric emissions factor for each animal group by using direct enteric CH_4 measurements to estimate 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 and is calculated as follows:

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

Where:

$EF_{Enteric_{i,j}}$	=	Enteric CH_4 emissions for animal group *j* on farm *i* during the monitoring period (kg CH_4)
$EF_{Production_{i,j}}$	=	Mean enteric emissions production factor for animal group *j* on farm *i* during the baseline or monitoring period (on-site direct measurement by chosen technology) (kg CH_4/head/d)
$N_{i,j}$	=	Mean number of head in each animal group *j* on farm *i* consuming a feed ingredient 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)

The baseline emissions production factor ($EF_{Production}$) may be measured prior to project implementation with a sample from each animal group subsequently included in the project. Alternatively, a control group for each animal group may 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 are 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 at the project location.

$EF_{Enteric_{i,j}}$ 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:

$$EF_{Enteric_{i,j}} = GEI_j \times \frac{Ym_j}{100} \times N_{i,j} \times Days_{i,j} \times \frac{1}{EC} \quad (3)$$

Where:

$EF_{Enteric_{i,j}}$	=	Enteric CH_4 emissions for animal group *j* on farm *i* during the monitoring period (kg CH_4)
GEI_j	=	Average gross energy intake of animal group *j* (MJ/head/d)
Ym_j	=	Conversion factor indicating the proportion of gross energy intake converted to enteric CH_4 energy by animal group *j* (dimensionless)
$Days_{i,j}$	=	Number of days spent on farm *i* by each animal in group *j* during the monitoring period (d)
$N_{i,j}$	=	Mean number of head in animal group *j* on farm *i* consuming a feed ingredient in the monitoring period (head)
EC	=	Energy content of methane (55.65 MJ/kg)

Gross energy intake (GEI) is calculated by multiplying dry matter intake (DMI) by the energy density of the feedstuff. It must be updated with any material change in feeding regime that alters gross energy intake.

$$GEI_j = DMI_j \times ED \quad (4)$$

Where:

GEI_j	=	Average gross energy intake of animal group *j* (MJ/head/d)

DMI_j	=	Average dry mass of feed consumed by animal group *j* in a given day (kg/head/d)
ED	=	Average energy density of dry matter (MJ/kg)

$EF_{Enteric_{i,j}}$ 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:

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

Where:

$EF_{Enteric_{i,j}}$	=	Enteric CH_4 emissions for animal group *j* on farm *i* during the monitoring period (kg CH_4)
$EF_{i,j}$	=	Average enteric CH_4 emissions factor for animal group *j* on farm *i* during the monitoring period (kg CH_4/head/d)
$N_{i,j}$	=	Mean number of head in animal group *j* on farm *i* consuming a feed ingredient 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 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:

$$PE_{Enteric_i} = \sum_j \left(EF_{Enteric_{i,j}} \times \left(1 - ERF_{Enteric_j}\right) \times \frac{GWP_{CH4}}{1000} \right) + EFME_i + EMA_i \tag{6}$$

Where:

$PE_{Enteric_i}$	=	Total project CH_4 emissions from livestock enteric fermentation on farm *i*, and from the production and transport of the ingredient used during the monitoring period (t CO_2e)
$EF_{Enteric_{i,j}}$	=	Enteric CH_4 emissions for each animal group *j* on farm *i* during the monitoring period, determined using Equations (**2**), (**3**), or (4) (kg CH_4)
$ERF_{Enteric_j}$	=	Reduction in enteric CH_4 emissions per animal in group *j* due to feed ingredient during the monitoring period (%)
GWP_{CH4}	=	Global warming potential of methane (dimensionless)
$EFME_i$	=	Total emissions associated with manufacturing and transport of feed ingredient for farm *i* during the monitoring period (t CO_2e)

EMA_i	=	Total emissions associated with manure decomposition for farm *i* during the monitoring period (t CO_2e)

8.2.1 Enteric Methane Emissions Reduction Factor ($ERF_{Enteric\_i,j}$)

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

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

Directly measure enteric methane to estimate methane production per animal group per day while consuming the feed ingredient during the monitoring period. The project proponent directly measures enteric methane (following the guidelines in Appendix 2) during the first monitoring period. The project proponent must provide the scientific protocol and the measurement data. This value is validated and then 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 ingredient is quantified using Equation (7), by comparing actual project performance to baseline enteric emission (Option 1 in Section 8.1).

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

Where:

$ERF_{Enteric_{i,j}}$	=	Reduction in enteric CH_4 emissions per animal in group *j* on farm *i* due to the feed ingredient during the monitoring period (%)
$EF_{Enteric_{i,j}}$	=	Enteric CH_4 emissions for each animal group *j* on farm *i* during the monitoring period, determined using Equations (**2**), (**3**), or (4) (kg CH_4)
$PEF_{i,j}$	=	Average enteric emissions production factor for animal group *j* on farm *i* during the monitoring period (on-site direct measurement by chosen technology) (kg CH_4/head/d)
$N_{i,j}$	=	Mean number of head in animal group *j* on farm *i* consuming a feed ingredient 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)

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

Apply the enteric emission reduction factor (%) of the feed ingredient and calculate emissions using Equation (5). The enteric emission reduction factor must be established through a meta-analysis of at least three peer-reviewed publications in journals that are listed in the Web of Science: Science Citation Index.[6] Project proponents must report the underlying information

[6] Available at: https://mjl.clarivate.com

related to the data selected from peer-reviewed literature for the meta-analysis and used to estimate emission reduction factors.[7]

The meta-analysis must consider dose, diet, production system, type of animal, and random variation, all of which influence the efficacy of feed additives. 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, neutral detergent fiber, housing). In the meta-analysis, meta-regressions for *ERF* may be derived to correct for measured variables within a project that are outside the 95% confidence interval (e.g., $ERF = a \times DMI + b$). Where there are significant differences in the project parameters that cannot be adjusted for in the meta-analysis, the project proponent must use Option 1 to obtain $ERF_{Enteric\_i,j}$.

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.[8] Otherwise, these emissions must be estimated as follows:

$$EFME_i = \frac{FM_i \times (EF_P + EF_{NO3})}{1000} + EF_{T_i} \tag{8}$$

Where:

$EFME_i$	=	Total emissions associated with manufacturing and transport of the feed ingredient for farm *i* during the monitoring period (t CO_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)
EF_{NO3}	=	Emission factor for production of nitrate-based products (kg CO_2e/kg)
EF_{T_i}	=	Emissions from transport to farm *i* of total feed ingredient consumed during the monitoring period (t CO_2e)

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

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

[7] For example, data must be representative of the project activity (i.e., equivalent geographic location, feed ingredient, herd structure, and feed regime). Otherwise, a justification for the data selection must be provided and approved.

[8] The pool or source may be excluded only where 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: https://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-04-v1.pdf).

Where:

EF_P	=	Emission factor for production of feed ingredient (kg CO_2e/kg)
Q_{Elec}	=	Quantity of grid electricity used by production facility per kilogram of feed ingredient produced during the monitoring period (MWh/kg)
EF_{Elec}	=	Electricity emission factor (kg CO_2/MWh)
Q_{ff_a}	=	Quantity of fossil fuel type *a* used at the production facility per kilogram of feed ingredient produced during the monitoring period (volume fuel/kg feed ingredient or kg fuel/kg feed ingredient)
FC_a	=	Energy content per unit of combusted fuel type *a* (TJ/volume or TJ/kg fuel)
EF_a	=	Emission factor for fuel type *a* (kg CO_2e/TJ)

Where values for the parameters in Equation (9) are not available, EF_P should be developed from one of the databases listed in Table 1 in the *FAO Environmental Performance of Feed Additives in Livestock Supply Chains*.[9]

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

$$EF_{T_i} = TEF_{i,m} \times D_{i,m} \times FM_i \tag{10}$$

Where:

EF_{T_i}	=	Emissions from transport to farm *i* of total feed ingredient consumed during the monitoring period (t CO_2e)
$TEF_{i,m}$	=	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/km)
$D_{i,m}$	=	Distance traveled 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)

Where values for the parameters in Equation (10) are not available, they should be developed using Section 6.5 of the *FAO Environmental Performance of Feed Additives in Livestock Supply Chains.*

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

Emissions from the feed ingredient are estimated by including all GHG sources from manure decomposition. Accounting for these GHG sources is not required for a project where such

[9] Available at: https://doi.org/10.4060/ca9744en

emissions are shown to be de minimis.[10] Otherwise, these emissions must be estimated as follows:

$$EMA_i = \left(CH4_i \times \frac{GWP_{CH4}}{1000}\right) + \left(N_2O_i \times \frac{GWP_{N2O}}{1000}\right) \tag{11}$$

Where:

EMA_i	=	Total emissions associated with manure decomposition for farm *i* during the monitoring period (t CO_2e)
$CH4_i$	=	Methane emissions from manure decomposition on farm *i* during the monitoring period (kg CH_4)
GWP_{CH4}	=	Global warming potential for methane (dimensionless)
N_2O_i	=	Direct N_2O emissions from manure decomposition on farm *i* during the monitoring period (kg N_2O)
GWP_{N2O}	=	Global warming potential for nitrous oxide (dimensionless)

Where 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:

$$CH4_i = \sum_{j,S} (N_{i,j} \times VS_{i,j} \times AWMS_{i,j,S} \times EF_{i,j,S}) \times 0.001 \tag{12}$$

Where:

$CH4_i$	=	Methane emissions from manure decomposition on farm *i* during the monitoring period (kg CH_4)
$N_{i,j}$	=	Mean number of head in animal group *j* on farm *i* consuming a feed ingredient in the monitoring period (head)
$VS_{i,j}$	=	Annual average excretion of volatile solids by animal group *j* on farm *i* during the monitoring period (kg/head)
$AWMS_{i,j,S}$	=	Fraction of total annual volatile solids from animal group *j* that is managed in manure system *S* on farm *i* (dimensionless)
$EF_{i,j,S}$	=	Emission factor for direct methane emissions from management system *S* of manure from animal group *j* on farm *i* (g CH_4/kg volatile solids)

Where 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:

[10] The pool or source may be excluded only where 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: https://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-04-v1.pdf).

$$N_2O_i = \left(\sum\nolimits_S \left(\sum\nolimits_j \left(N_{i,j} \times Nex_j \times AWMS_{i,j,S}\right) + N_{cdg(S)}\right) \times EF_{3,S}\right) \times \frac{44}{28} \quad (13)$$

Where:

N_2O_i	=	Direct N_2O emissions from manure decomposition in farm *i* during the monitoring period (kg N_2O)
$N_{i,j}$	=	Mean number of head in animal group *j* on farm *i* consuming a feed ingredient in the monitoring period (head)
Nex_j	=	Annual average nitrogen excretion per head in animal group *j* (kg N/head)
$AWMS_{i,j,S}$	=	Fraction of total annual volatile solids from animal group *j* managed in manure system S on farm *i* (dimensionless)
$N_{cdg(S)}$	=	Annual nitrogen input via co-digestate, where S is anaerobic digestion (kg N)
$EF_{3,S}$	=	Emission factor for direct N_2O emissions from manure management system *S* (kg N_2O-N/kg N)
44/28	=	Conversion of N_2O-N emissions to N_2O emissions

8.3 Leakage

Leakage may occur due to a change in the number of animals in the livestock operation resulting from impacts on livestock performance from introducing the feed ingredient. This necessitates 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 GHG emission reductions and thus do not need to be accounted for. 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 Reductions and Removals

Net GHG emission reductions (“reductions”) are calculated as follows:

$$ER_{Enteric} = \sum\nolimits_i BE_{Enteric_i} - PE_{Enteric_i} \quad (14)$$

Where:

$ER_{Enteric}$	=	Total GHG emission reductions due to project activities during the monitoring period (t CO_2e)
$\mathrm{BE}_{\mathrm{Enteric}_i}$	=	Total baseline CH_4 emissions from livestock enteric fermentation on farm *i* during the monitoring period (t CO_2e)

$PE_{Enteric_i}$ = Total project CH_4 emissions from livestock enteric fermentation on farm *i*, and from the production and transport of the ingredient used during the monitoring period (t CO_2e)

9 MONITORING

9.1 Data and Parameters Available at Validation

Data/Parameter	NDF_j
Data unit	Percentage dry matter
Description	Neutral Detergent Fiber. 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 statistics
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	None

Data/Parameter	GWP_{CH4}
Data unit	dimensionless
Description	Global warming potential of methane
Equations	(1), (6), (11)
Source of data	100-year time horizon IPCC defaults to be taken from the most recent IPCC report

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 and project emissions
Comments	None

Data/Parameter	GWP_{N2O}
Data unit	dimensionless
Description	Global warming potential of nitrous oxide
Equations	(1), (6), (11)
Source of data	100-year time horizon IPCC defaults to be taken from the most recent IPCC report
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 and project emissions
Comments	None

Data/Parameter	$EF_{Production_{i,j}}$
Data unit	kg CH_4/head/d
Description	Mean enteric emissions production factor for animal group *j* on farm *i* during the baseline or monitoring period (on-site direct measurement by chosen technology)
Equations	(2)
Source of data	Data records and farm operations report

Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	To quantify project enteric CH_4 production per animal, samples for each group are selected to be directly measured. 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 considered when reporting the final value. Parameter to be reassessed for each crediting period. Where the value is no longer representative, it must be updated. New data must be collected where the value is no longer representative due to changes in geographic location or material changes in the following management practices: • Feeding regime (e.g., type and quality resulting in changes to total DMI intake and nutritional value) • Animal group (e.g., species, breed) • Weight (i.e., variations on weight of more than 5%) • Number of animals • Production phase (i.e., resulting in any changes in the number of days that an animal remains in the feed dock receiving the feed ingredient) Where the change in value is due to changes in the experimental design and sample size of the population, project proponents must: 1) use appropriate significance tests (e.g., paired or unpaired t-test) to demonstrate that $EF_{Production\_i,j}$ changes by less than 5% from the value in the previous monitoring period. 2) Update the parameter by increasing it as per the results of the test. In case of no clear results, 50% uncertainty must be added. 3) report and justify the test used, and report sample sizes and standard variations, p-values and confidence intervals, and interpretation of significance.
Purpose of data	Calculation of baseline and 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 with an MSc or PhD and professional/research experience in the relevant discipline).

Data/Parameter	Ym_j
Data unit	dimensionless
Description	Conversion factor indicating the proportion of gross energy intake converted to enteric CH_4 energy by animal group *j*
Equations	(3)
Source of data	National or regional and population-specific *Ym* values should be used where available, to better reflect ruminant population characteristics. Default values provided in Table 5 (Appendix 3) may be used 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. These values must be used where direct applicability is demonstrated. IPCC default values for *Ym* (Table 5 in Appendix 3) are provided for different animal categories and may be used where values from country-specific research are not available. Table 5 provides *Ym* values derived from cattle with diets containing various levels of neutral detergent fiber (NDF) and digestible energy (DE). The NDF values of the feed used in the project must be available in order to use Table 5. 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. Where using data from Table 5, adjusted *Ym* values must be applied and no further uncertainty deduction is required. Since a 20% uncertainty discount for dairy and nondairy cows, buffalo, sheep and goats have been applied Where using data from other sources, the most conservative uncertainty value of the data sources must be applied. Where uncertainty values are not available, a 50% default uncertainty must be applied. Parameters to be updated for each crediting period where new data exists. Any shift in animal group to those with different enteric fermentation profiles must be reported.
Purpose of data	Calculation of baseline emissions
Comments	None

Data/Parameter	*EC*
Data unit	MJ/kg
Description	Energy content of methane
Equations	(3)
Source of data	Default value taken from *2006 IPCC Guidelines for National Greenhouse Gas Inventories*[11]
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	*ED*
Data unit	MJ/kg
Description	Average energy density 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: • 19.10 MJ/kg for diets including edible oils with 4–6% fat content • 18.45 MJ/kg 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

[11] Volume 4, Chapter 10, Section 10.3.2. Available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

Comments	None

Data/Parameter	$EF_{i,j}$
Data unit	kg CH_4/head/d
Description	Average enteric CH_4 emissions factor for each animal in group *j* on farm *i* during the monitoring period
Equations	(5), (12)
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 where regional values are not available.
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	Where using peer-reviewed literature to obtain values, data must be published in journals on the Web of Science: Science Citation Index. Parameters from any source (e.g., IPCC, 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	None

Data/Parameter	$PEF_{i,j}$
Data unit	kg CH_4/head/d
Description	Average enteric emissions production factor for animal group *j* on farm *i* during the monitoring period (on-site direct measurement by chosen technology)
Equations	$ERF_{Enteric_{i,j}} = \frac{EF_{Enteric_{i,j}} - (PEF_{i,j} \times N_{i,j} \times Days_{i,j})}{EF_{Enteric_{i,j}}} \times$
Source of data	Data records and farm operations report

Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	A sample for each animal 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 considered when reporting the final value. Parameter to be reassessed for each crediting period. Where the value is no longer representative, it must be updated. New data must be collected where the value is no longer representative due to changes in geographic location or material changes in the following management practices: • Feeding regime (e.g., type and quality resulting in changes to total DMI intake and nutritional value) • Animal group (e.g., species, breed) • Weight (i.e., variations of more than 5%) • Number of animals • Production phase (i.e., changes in the number of days that an animal remains in the feed dock receiving the feed ingredient) Where the value is no longer representative due to changes in the experimental design and sample size of the population, project proponents must: 1) use appropriate significance tests (e.g., paired or unpaired t-test) to demonstrate that the change in $PEF_{i,j}$ is below 5%. OR 2) Update the parameter by increasing it as per the results of the test. In case of no clear results, 50% uncertainty must be applied. Report and justify the test used, and report sample sizes and standard variations, p-values and confidence intervals, and interpretation of significance.
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 animal science, livestock health, or nutrition with an MSc or PhD and professional/research experience in the relevant discipline).

Data/Parameter	EF_{NO3}
Data unit	kg CO_2e/kg
Description	Emission factor for production of nitrate-based products
Equations	(8))
Source of data	Feng and Kebreab (2020); Menegat et al. (2022)
Value applied	2.0
Justification of choice of data or description of measurement methods and procedures applied	LCA studies estimate that calcium nitrate production emissions vary from 0.67 to 1.76 kg CO_2e/kg. The value applied in the methodology is conservative.
Purpose of data	Calculation of project emissions
Comments	Includes all activities involved at the manufacturer's facility to produce the feed ingredient.

9.2 Data and Parameters Monitored

Data/Parameter	*j*
Data unit	Count
Description	Animal group
Equations	(1)(2), (2), (3), (4), (5), (6), (7), (12), (13)
Source of data	Data records of livestock operations using project feed ingredient
Description of measurement methods and procedures to be applied	Ruminant populations at each farm *i* must be grouped based on a homogeneous characteristic. 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 that 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.[12]
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 method	N/A
Comments	None

Data/Parameter	$N_{i,j}$
Data unit	Head
Description	Mean number of head in each animal group *j* on farm *i* consuming a feed ingredient in the monitoring period
Equations	(2), (2)(3), (5), (7), (12), (13)
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, considering animal entry to and exit 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 consuming the feed ingredient in each animal group. Measured by averages calculated from annual records.

Days on feed	Days x head	Number of head
1	(1 x 100)	1 x 100
2	(1 x 98)	1 x 98
3	(1 x 103)	1 x 103
Total = 3	Total = 301	Mean = 100

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

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 and project emissions
Calculation method	N/A
Comments	Monitoring is established at the feed purchaser level. An appropriate and unique identification system for the purchasers (e.g., including project proponent name, tax identification number, number of animals in each group, unique invoice number and date) avoids 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.

Data/Parameter	$Days_{i,j}$
Data unit	days
Description	Number of days spent on farm *i* by each animal in group *j* during the monitoring period
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.
Purpose of data	Calculation of baseline emissions
Calculation method	N/A
Comments	The number of days may be less than 365 (e.g., for young cattle, the number of days represents the length of stay in specific animal group *j*).

Data/Parameter	DMI_j
Data unit	kg dry matter/head/d
Description	Average dry mass of feed consumed by animal group *j* 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 statistics
Description of measurement methods and procedures to be applied	Data must be provided by the livestock operator or associated partners for each animal group. Farm records must document the average daily dry matter intake for each animal group in the project.
Frequency of monitoring/recording	Parameter to be updated when any material changes in feeding regime (e.g., average dry mass of feed consumed by the animal group) occur.
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 method	N/A
Comments	None

Data/Parameter	FM_i
Data unit	kg
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 (e.g., including client name, unique invoice number and date, feed purchase receipts, weights, and/or feed delivery records). Delivery notes, invoices, and sales records must be cross-checked between buyer and seller to verify the integrity of records.

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	None

Data/Parameter	Q_{Elec}
Data unit	MWh/kg
Description	Quantity of grid electricity used by production facility per kilogram of feed ingredient produced during the monitoring period
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 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. Where product line-level data are not available, the manufacturer may 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 feed ingredient, monthly production output data must be available to the manufacturer.
Purpose of data	Calculation of project emissions
Calculation method	N/A
Comments	None

Data/Parameter	Q_{ff_a}
Data unit	Volume fuel/kg feed ingedient or kg fuel/kg feed ingredient
Description	Quantity of fossil fuel type *a* used at the production facility per kilogram of feed ingredient produced during the monitoring period
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. Where product line-level data are not available, the manufacturer may 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	None

Data/Parameter	EF_{elec}
Data unit	kg CO_2/MWh
Description	Electricity emission factor
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 most recent version of VCS tool *VT0011 Electricity System Emission Factors* may be used to determine EF_{elec} where national or state/province data are not available.

Data/Parameter	FC_a
Data unit	TJ/volume or TJ/kg fuel
Description	Energy content per unit of combusted 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 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	None

Data/Parameter	EF_a
Data unit	kg CO_{2e}/TJ
Description	Emission factor for 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.
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 during the crediting period (using a project description deviation) where more recent information becomes available.

Data/Parameter	$TEF_{i,m}$
Data unit	t CO_2/kg/km
Description	CO_2 emitted by transport mode *m* per kilogram of feed ingredient delivered to and consumed on farm *i* during the monitoring period

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 reductions); 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	None

Data/Parameter	$D_{i,m}$
Data unit	km
Description	Distance traveled by transport mode *m* delivering feed ingredient consumed on farm *i* during the monitoring period
Equations	(10)
Source of data	Data provided by the project proponent or manufacturer
Description of measurement methods and procedures to be applied	Where the feed ingredient goes through a feedmill, 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 parameter may not be needed, as it is assumed it is embedded into the LCA calculations.

Data/Parameter	$VS_{i,j}$
Data unit	kg/head/yr
Description	Annual average excretion of volatile solids by 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 reductions); and the process by which the data have been peer-reviewed (preferred) or proposed by national recommendations for cattle nutrient requirements. Where 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*[13] 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

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

Calculation method	N/A
Comments	None

Data/Parameter	$AWMS_{i,j,S}$
Data unit	dimensionless
Description	Fraction of total annual volatile solids from animal group *j* that is managed in manure management system *S* on farm *i*
Equations	(12), (13)
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 reductions); and the process by which the data have been peer-reviewed (preferred). Where 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*.[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
Comments	None

Data/Parameter	$EF_{i,j,S}$

[14] 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

Data unit	g CH_4/kg
Description	Emission factor for direct CH_4 emissions from management system S of manure from 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 reductions); and the process by which the data have been peer-reviewed (preferred). Where regionally specific data cannot be collected or derived, default values may be derived from the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.[15]
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	None

Data/Parameter	Nex_j
Data unit	kg N/head/yr
Description	Annual average nitrogen excretion per head in animal group *j*
Equations	(13)
Source of data	Regional or national default values from recognized sources

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

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 reductions); and the process by which the data have been peer-reviewed (preferred). Where 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*[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	None

Data/Parameter	$EF_{3,S}$
Data unit	kg N_2O-N/kg N
Description	Emission factor for direct N_2O emissions from manure management system *S*
Equations	(13)
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 reductions); and the process by which the data have been peer-reviewed (preferred).

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

	Where 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*[17] 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	None

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 reductions have been fed with the appropriate quantity of feed ingredient. Thus, project proponents must provide detailed feeding records as per manufacturer instructions 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 trace the feed ingredient back to the manufacturer.

Direct enteric methane emissions must be measured using state-of-the-art technologies, which are well-documented in peer-reviewed publications. See Table 4 in Appendix 2 for examples.

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.

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

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APPENDIX 1: ACTIVITY METHOD

Initial assessment indicates that there is not enough activity globally that would put activity penetration above the 5% threshold required under the VCS Program. Several barriers limit the widespread adoption of feed ingredients that inhibit or suppress enteric methane (Paarlberg 2025; Toensmeier 2024). However, in some areas (Europe, United States, Canada, Australia, and New Zealand), policies have been implemented to expedite the adoption of feed ingredients to reduce GHG emissions from livestock production systems (Table 2). This, combined with the commercial availability of specific feed ingredients (e.g., 3-NOP), may promote the use of such products. Table 2 provides a summary of the current estimated activity penetration by region and product and lists the sources of information.

Table 2. Estimated penetration rate of feed ingredients by region and product

Country/ Region	Estimated Activity Penetration (%)	Product	Sources
Europe	>5–10%	3-NOP (Bovaer®) uptake in dairy farm growing via CAP and ESG reporting incentives	Hardy (2024); DSM-Firmenich (2023); EFSA Panel on Additives and Product Substances used in Animal Feed et al. (2021)
United States	>5%	3-NOP (Bovaer®) approved in 2023 in dairy; limited use due to costs and lack of regulatory frameworks	Elanco (2024); FAO (2023)
Canada	~10–15%	Adoption is rising under OFCAF, especially in Alberta and Quebec.	Agriculture and Agri-Food Canada (2022); Farmonaut (2025)
Australia	~5%	Seaweed-based additives in pilot and precommercial phases	Commonwealth of Australia (2024); Hewitt (2025)
New Zealand	~10–15%	Full rollout by 2026. Current use is pilot phase.	Fonterra (2023); Global Dairy Farmers (2025)
Latin America	<2%	Regulatory access and supply chains are still nascent.	Fontagro (2022); IDB (2022)
India and South Asia	<1%	No commercial use; research and development stage only.	ICAR (2025)

Country/ Region	Estimated Activity Penetration (%)	Product	Sources
Sub-Saharan Africa	<1%	No structured application; academic trials only.	ILRI (2025)

A1.1 Positive List

This project activity is a relatively new field with few, if any, fully commercial technologies. Thus, the methodology uses an activity method for demonstrating additionality, with the technology (the feed ingredient) as the basis for a positive list. The total number of ruminants fed with a feed ingredient that inhibits methanogenesis must 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, v4.4* and is determined by taking the observed activity (OA) divided by the maximum adoption potential (MAP). Where this is less than 5%, the project activity may be considered additional.

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

Where:
AP_y = Activity penetration of the project activity in year y (%)
OA_y = Observed adoption of the project activity in year y (head)
MAP_y = Maximum adoption potential of the project activity in year y (head)

A1.1.1 Maximum Adoption Potential of the Project Activity in Year *y*

The *VCS Methodology Requirements, v4.4* 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, the maximum adoption potential of this activity may be limited to ruminants that have been reared for meat and dairy production worldwide, due to market access and implementation constraints (e.g., necessary infrastructure for transporting the feed ingredient to the farm, 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,[18] of which approximately 2.67 billion were used for meat and dairy products (Table 3).

[18] The global population of cattle, sheep, goat, and buffalo in 2019 was estimated to be 4 438 416 429 (data retrieved in 2021, from http://www.fao.org/faostat/en/#data).

Table 3. 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,[19] grazing animals supply about 30% of global production of beef and about 23% of global production of lamb and mutton. For this analysis, it is conservatively assumed that 30% of buffalo and goat meat production also comes from grazing animals. The dispersed nature of livestock for long time periods in grazing conditions limits the ability to regularly administer feed ingredients. In theory, feed ingredients could be administered to some percentage of grazing animals (e.g., through animal mineral blocks). However, grazing animals can be conservatively excluded from the calculation of *MAP*. Dairy animals are not excluded as they can have daily access to feed in the milking parlor. Therefore, the maximum adoption potential of this activity is limited to MAP_y = 2 182 878 026.

A1.1.2 Observed Adoption of the Project Activity in Year *y*

A few dietary strategies have been proposed to lower methane production in ruminants (Kreuzer 2025; Prado et al. 2025; Toensmeier 2024; FAO 2023; Knapp et al. 2014; Boadi et al. 2004). Most are not commercially available and/or have no impact on enteric fermentation. Currently, only a few products have been observed in the market. 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.[20] By 2018, a different product consisting of a blend of essential oils that

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

[20] FeedInfo News Service. 2010. "Interview: France's Valorex Extracts Value from Overlooked Grains." Accessed 7 September 2025. http://www.pinallet.com/data/FEEEDINFO%20Interviews%20VALOREX%20CEO.pdf

claims to reduce methane production by cattle had reached approximately one million cattle.[21] Neither of these examples report on the reduction in enteric emissions via a reduction in methanogenesis. Conversely, the use of methane inhibitors recently received approval for commercial use in specific geographic areas with restricted uptake (only given to around 250 000 cattle worldwide[22]). For the purposes of demonstrating additionality, it is assumed that the project activities are the same (i.e., feed ingredients reducing enteric emissions via reduction in methanogenesis). To be conservative, it is assumed that the published reports only capture half of all enteric emission reduction activities, which results in an estimated activity of 2.6 million ruminants.

Therefore:

$$AP_y = OA_y / MAP_y \times 100$$
$$AP_y = 2\,600\,000 \div 2\,182\,000\,000 \times 100$$
$$AP_y = 0.119\%$$
$$AP_y < 5\%$$

Given the current ruminant population and commercially available feed ingredients, particularly 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 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), the project proponent must demonstrate that the project activity faces barriers to its uptake, per VCS Program rules. The 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.
2) Project activity implementation requires purchase of the feed ingredient, which adds to farmers' existing variable costs. Farmers make multiple decisions in the agricultural cycle about the adoption of products and practices. 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

[21] Munda, A. 2018. "Swiss Company Develops New Cow Feed to Cause Fewer Farts." *The Green Optimistic*. Accessed 15 December 2021. https://www.greenoptimistic.com/swiss-company-develops-new-cow-feed-fewer-farts-20181006/#.XF

[22] TheBullVine. 2024. "Interview: Who Will Foot the Bill for Methane-reducing Feed Additives in Dairy Farming?" Accessed 7 September 2025. https://www.thebullvine.com/management/who-will-foot-the-bill-for-methane-reducing-feed-additives-in-dairy-farming/

the uncertain costs of adopting it (Loevinsohn et al. 2013). 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 (plants or algae) that occur during a certain time of year (seasonal crops). Working capital can fluctuate widely, which can lead to an unacceptably high risk to technology availability. 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.

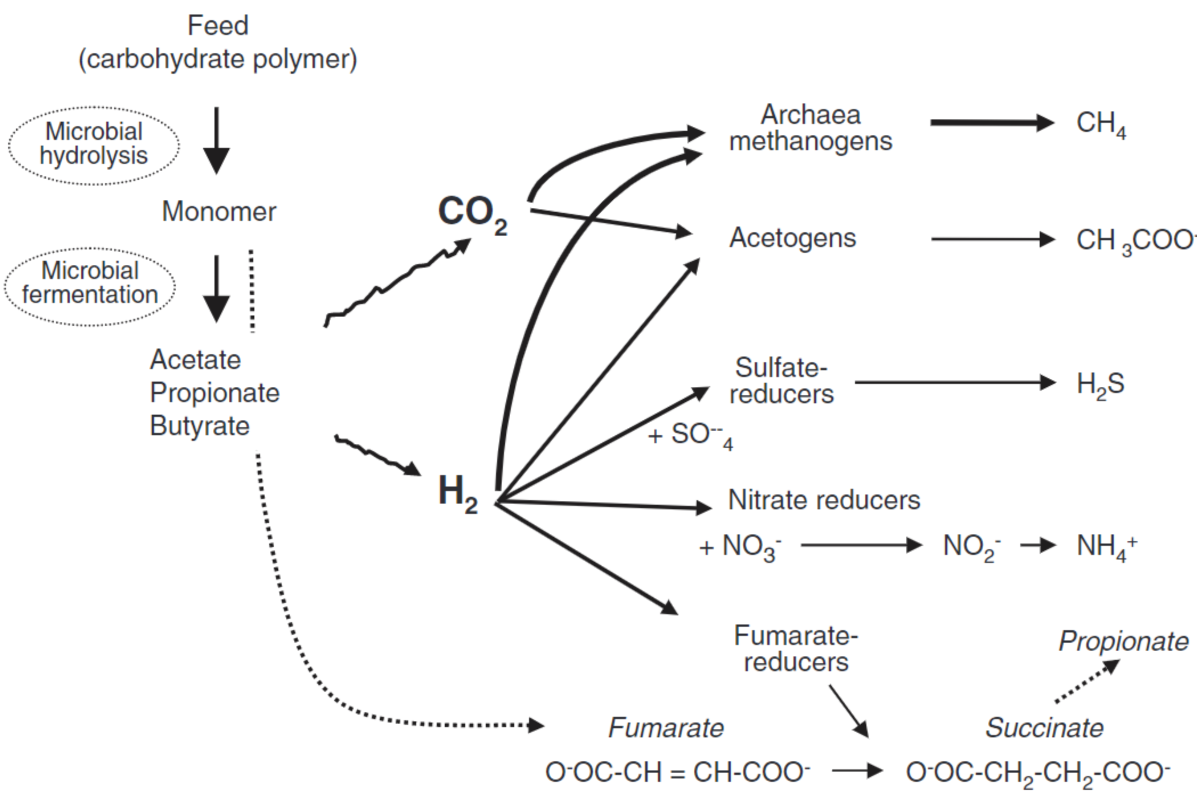
APPENDIX 2: BACKGROUND INFORMATION ON PROJECT ACTIVITY

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 due to fermenting feed material in the rumen. These enteric emissions from ruminants 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 illustrates 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. 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)



A2.1 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 literature. This includes respiration chambers, 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), use spot measurement of gas concentrations in samples of exhaled air at certain time points. A single spot measurement is not sufficient; repeated measurements are required and can be taken whilst the animals are feeding or standing. There are diverse technologies 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.

Where 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 measure enteric methane directly. Baseline enteric CH_4 emission may still be set using Options 2 or 3 as described in Section 8.1. The chosen measurement technology and measuring procedures must meet the following conditions:

1) The technology is well-documented 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 are reported under project conditions.
4) The project proponent or associated partner demonstrates technical skills and experience in directly measuring enteric methane to generate accurate results.
5) The recommended measurement protocol determines optimal sample size. Using too few animals may limit ability to detect significant differences that may exist in the population. The following formula may 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	=	Standard deviation from previous studies or pilot studies to measure variability between animals
d	=	Minimum expected difference between the observed means of two groups (baseline versus project)

   Detailed information on optimal sample size calculation is given in Charan and Kantharia (2013).
6) The recommended measurement protocol determines recording duration. The minimum trial duration is eight weeks. 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 (sampling day 1), 0300, 1200, and 1700 (sampling day 2), and 0000 and 0500 (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*.[23]

Table 4 describes three examples of different technologies for direct measurement of enteric methane emissions and calculation of emission reductions, following a specific scientific protocol.

Table 4. Examples of technologies for measuring enteric methane emissions

Type of measurement method/technology	Description
Respiration chamber	Respiration chambers are used to measure CH_4 from 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 (e.g., 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 SF_6:CH_4 ratio of the gas (Hristov et al. 2015). SF_6 is a powerful greenhouse gas and should be used responsibly with 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.

[23] CDM Meth Panel. 2008. Thirty-second Meeting Report, Annex 14. https://cdm.unfccc.int/Panels/meth/meeting/mp_08.html#032

APPENDIX 3: PERCENTAGE OF GROSS ENERGY IN FEED CONVERTED TO METHANE (YM) IN ANIMAL GROUPS

Ym is defined as the percentage of gross energy intake by a ruminant that is converted to methane in the rumen. National environmental agencies or similar government and research institutions may have accurate peer-reviewed studies that provide *Ym* values.

Table 5 provides default values for CH_4 conversion rates for different animal categories (from Tables 10.12 and 10.13 of Chapter 10, Vol. 4 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*) that may be used where values are not available from country-specific research. These estimates are based on general feed characteristics and production practices found in developed or developing countries and consider both digestible energy (DE) and neutral detergent fiber (NDF). The lower bounds must be used for good quality food (i.e., high digestibility and energy value). Higher bounds are more appropriate for poorer quality feed. NDF is often considered a good determinant of quality as 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 5. Livestock CH_4 conversion factors

Livestock category	Feed quality		*Ym*[24] (%)	Adjusted *Ym* (%)
	Digestible energy (%)	Neutral detergent fiber (% DMI)		
Dairy cows and buffalo	≥70	≥35	6.0	4.80
	63–70	>37	6.3	5.04
	≤62	>38	6.5	5.2
Nondairy and multi-purpose cattle and buffalo	≤62		7.0	5.6
	62–71		6.3	5.04
	≥72		4.0	3.20
	>75		3.0	2.40
Sheep	N/A		6.7	5.36
Goats	N/A		5.5	4.40

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

APPENDIX 4: ENTERIC FERMENTATION EMISSION FACTORS FOR LIVESTOCK

Table 6 shows a range of enteric fermentation emission factors for cattle and buffalo based on typical regional conditions and productivity systems. Table 7 shows enteric fermentation emission factors for sheep and goats by production system type.

Table 6. Tier 1 and Tier 1a enteric fermentation emission factors for cattle and buffalo ($kg\ CH_4$/head/yr)

Region	Livestock	Emission Factor	Adjusted Emission Factor*
North America	Dairy cattle	138	96.6
	Other cattle	64	44.8
Western Europe	Dairy cattle	126	88.2
	Other cattle	52	36.4
	Buffalo	78	54.6
Eastern Europe	Dairy cattle	93	65.1
	Other cattle	58	40.6
	Buffalo	68	47.6
Oceania	Dairy cattle	93	65.1
	Other cattle	63	44.1
Latin America	Dairy cattle	87	60.9
	High productivity systems	103	72.1
	Low productivity systems	78	54.6
	Other cattle	56	39.2
	High productivity systems	55	38.5
	Low productivity systems	58	40.6
	Buffalo	68	47.6
Asia	Dairy cattle	78	54.6
	High productivity systems	96	67.2
	Low productivity systems	71	49.7
	Other cattle	54	37.8
	High productivity systems	43	30.1
	Low productivity systems	56	39.2
	Buffalo	76	53.2

Africa	Dairy cattle	76	53.2
	High productivity systems	86	60.2
	Low productivity systems	66	46.2
	Other cattle	52	36.4
	High productivity systems	60	48.0
	Low productivity systems	48	38.4
Middle East	Dairy cattle	76	60.8
	High productivity systems	94	75.2
	Low productivity systems	62	49.6
	Other cattle	60	42.0
	High productivity systems	61	42.7
	Low productivity systems	55	38.5
Indian subcontinent	Dairy cattle	73	51.1
	High productivity systems	70	49.0
	Low productivity systems	74	51.8
	Other cattle	46	32.2
	High productivity systems	41	82.7
	Low productivity systems	47	32.9
	Buffalo	85	59.5

*All estimates have an uncertainty of ±30%. Source: IPCC. 2019. *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10, Table 10.11.

Table 7. Tier 1 enteric fermentation emission factors for sheep and goats (kg CH_4/head/yr)

Livestock	Emission Factor		Adjusted Emission Factor	
	High Productivity System	Low Productivity System	High Productivity System	Low Productivity System
Sheep	9	5	4.5	2.5
Goat	9	5	4.5	2.5

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

DOCUMENT HISTORY

Version	Date	Comment
v1.0	22 Nov 2019	Initial version
v2.0	21 Dec 2021	• Expands applicability conditions to include any type of feed additive approved for animal use and with scientifically demonstrated efficacy. • Increases the stringency of procedures by which project proponents establish the enteric methane emission reduction factor.

v3.0 (draft)	8 October 2025	• Updates the approach for the additionality assessment:
		  ○ Updates the positive list based on activity penetration by geographic region
		  ○ Includes a project method approach for projects located in regions not covered by the positive list
		  ○ Expands guidance on applicability conditions
		• Updates the project boundary to include:
		  ○ nitrous oxide emissions from the production and transportation of nitrate-based feed ingredients
		  ○ nitrous oxide and methane emissions from manure decomposition
		• Aligns quantification approaches for baseline and project emissions
		• Revises default values and criteria for parameters used for calculating enteric methane emission reductions (i.e., enteric emissions per animal group, $EF_{Enteric}$; average gross energy intake, GEI; conversion factor *Ym*, average energy density *ED* of dry matter intake *DMI*).
		• Adapts and clarifies monitoring requirements for baseline and project emissions