RUMENSIN®
DAIRY CATTLE FEED ADDITIVE PROTOCOL

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PRO-00000001	1.0	October 27, 2023

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Table of Contents

1 Introduction

The Rumensin Feed Additive Protocol was developed by Elanco to provide guidance for the creation of greenhouse gas (GHG) reductions associated with the use of Rumensin as a feed additive for U.S. dairy cattle. Rumensin improves milk production efficiency in dairy cows and reduces GHG emissions generated from enteric fermentation. It also has a secondary effect on both GHG emissions from feed cultivation and manure through improvements in feed efficiency and decreased manure production.

Methane (CH_4) is a GHG with a global warming potential 27 times that of CO_2 on a 100-year time-horizon.[1] Enteric fermentation was the largest anthropogenic source of methane emissions in the U.S. in 2021, and enteric emission from dairy cattle have increased 13.4% from 1990 to 2021.[2] Therefore, the dairy industry has undertaken initiatives to reduce GHG emissions from its products. In 2020, Dairy Management Inc. representing the U.S. dairy industry launched the Net Zero Initiative to "achieve industrywide neutral or better GHG emissions, optimize water usage, and significantly improve water quality by 2050."[3] Meeting these goals will be challenging because rising global demand for meat and milk has contributed to an increase in CH_4 emissions since 1990.[4] Looking ahead, the United Nations Food and Agriculture Organization (FAO) estimates that the demand for meat and milk in 2050 will be 73 and 58 percent more, respectively, than the demand in 2010.[5] To combat climate change, the agriculture sector needs to dramatically reduce CH_4 emissions.

Elanco is a global leader in animal health dedicated to innovating and delivering products and services to prevent and treat disease in farm animals, creating value for farmers, stakeholders, and society as a whole. Elanco developed this protocol to provide guidance and quantifications of GHG reductions associated with the use of Rumensin in dairy cattle. The sale of these credits should incentivize project developers to pursue GHG reductions from cattle. The protocol credits these reductions in a complete, consistent, transparent, and accurate manner.

2 Project Definition and Eligibility

This protocol credits the GHG reductions created by the practice of feeding Rumensin to U.S. dairy cattle. Rumensin is a feed additive approved by the U.S. Food and Drug Administration Center for Veterinary Medicine for improved milk production efficiency, defined as production of marketable solids-corrected milk per unit of feed intake corrected for changes in body weight. In growing cattle (including replacement heifers), Rumensin increases rate of weight gain and prevents and controls coccidiosis.

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[1] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp.

[2] EPA (2023) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas emissions-andsinks-1990-2021.

[3] National Milk Producers Federation. Climate Policy. https://www.nmpf.org/issues/sustainability/climate-policy

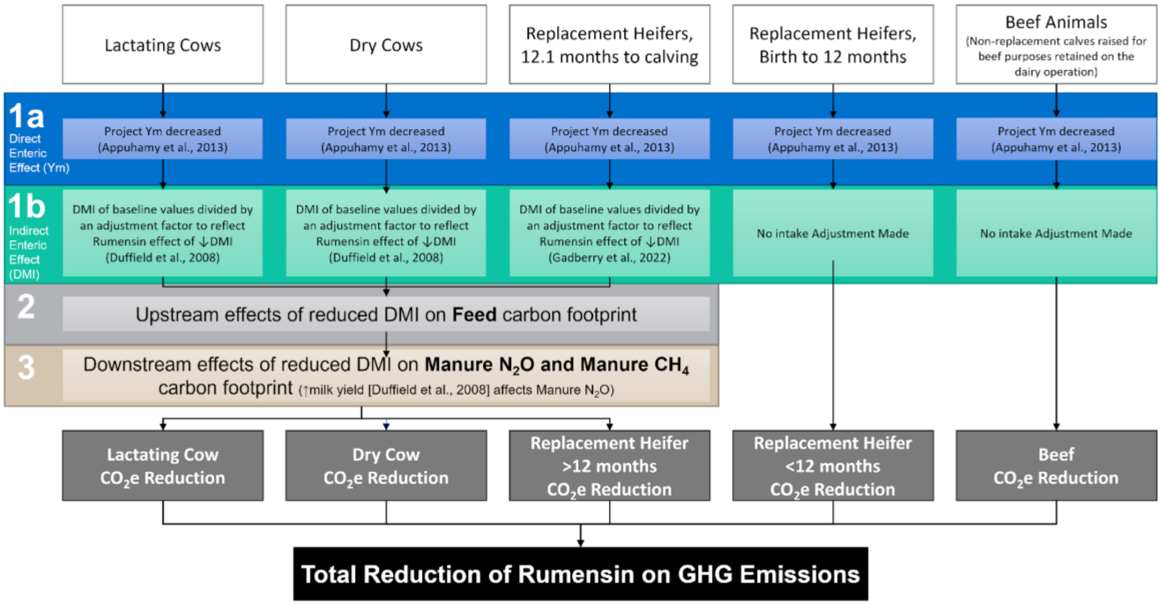
[4] Our World in Data. Greenhouse gas emissions. https://ourworldindata.org/greenhouse-gas-emissions#annual-methane-emissions-how-much-do-we-emit-each-year

[5] UN FAO (2013) Tackling Climate Change Through Livestock. http://www.fao.org/3/i3437e/i3437e.pdf

2.1 Rumensin Effects on Methane and Productivity

Rumensin improves milk production efficiency in dairy cows by shifting rumen bacterial populations to produce more propionate which is a more efficient use of feedstuffs because there is a reduction in the amount of energy spent as carbon dioxide and methane. Figure 2.1 depicts a summary of all assumptions and adjustments with Rumensin implementation as well as their references.

Figure 2.1 *Summary of adjustments utilized to quantify the effect of Rumensin on GHG emissions*



2.1.1 Rumensin Impact on Productivity

A meta-analysis on the impact of Rumensin on productivity outcomes in lactating dairy cattle was conducted using 71 trials containing data from 255 trial sites and 9,677 cows examining milk production and composition.[6] A wide range of doses encompassing the 11-22 g/ton DM dose requirement outline in this protocol (section 3) were represented. Studies lacking a control group, randomization, or reporting of measures of dispersion or *P*-values were excluded from consideration in the analysis. Rumensin use in dry and lactating dairy cattle significantly decreased dry matter intake (DMI) by 2.3% and increased milk yield by 2.3%. Because significant heterogeneity was observed with milk components, the reported yield and component percentages were used to calculate solids-corrected milk (SCM) differences between control and Rumensin treatments, resulting in a 0.5% increase in SCM with Rumensin. Therefore, throughout this protocol a conservative positive increase of 0.5% was utilized for Rumensin's effect on both SCM and milk yield. A 4.5% reduction in DMI was observed with Rumensin in a meta-analysis by Gadberry et al. (2022) encompassing both beef and dairy replacement heifers fed Rumensin at 200 mg/head/day. A conservative approach was taken by not including the Rumensin DMI effect on beef animals (non-replacement calves raised for beef purposes retained on the dairy operation). Additionally, a conservative method was utilized in replacement heifers by only accounting for Rumensin's DMI effect in replacement heifers greater than 12 months old as the beneficial effect of energy in younger animals is often reflected more in weight gain than DMI reduction. A summary of Rumensin impacts on productivity are highlighted in Tables 2.1 and 2.2.

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[6] Duffield, T.F. et al. (2008) A Meta-Analysis of the Impact of Monensin in Lactating Dairy Cattle. Part 2. Production Effects. J. Dairy Sci. 91:1347-1360.

Table 2.1 *Rumensin's impact on productivity according to Duffield et al. (2008) meta-analysis and SCM calculations outline in Equations 5.40 through 5.51*

Metric	Reported Rumensin Effect	Reported % Change	Calculated Control Value	Calculated Rumensin Value	Calculated % Change
Dry Matter Intake, kg/d	-0.3	-2.3%	13.04	12.74	-
Milk Production, kg/d	+0.7	+2.3%	30.43	31.13	-
Fat %	-0.12	-3.1%	3.87	3.75	-
Protein %	-0.03	-0.9%	3.33	3.30	-
Lactose %	-0.012	-0.25%	4.80	4.79	-
Fat Yield, kg/d			1.18	1.17	
Protein Yield, kg/d			1.01	1.03	
Solids-Corrected Milk, kg/d	**-**	**-**	**29.85**	**29.99**	**+0.5%**

Table 2.2 *Rumensin's impact on dry matter intake and productivity*

Metric	Cattle Type	Rumensin Effect	Reference
Milk Production (Milk Or SCM)	Lactating Cows	+0.5%[7]	Duffield et al., 2008
Dry Matter Intake	Lactating Cows	-2.3%	Duffield et al., 2008
Dry Matter Intake	Dry Cows	-2.3%	Duffield et al., 2008
Dry Matter Intake	Replacement Dairy Heifers 12.1 Months To Calving	-4.3%	Gadberry et al., 2022

2.1.2 Rumensin Impact on Methane Production

Rumensin's mode of action for milk production efficiency results in reduced methane production. The impacts of feeding Rumensin to cattle include both a direct reduction in CH_4 emissions from enteric fermentation and an indirect reduction in enteric fermentation emissions through decreased DMI with no negative effects on health and a positive benefit to milk production. The persistent benefit of feeding cattle Rumensin is supported by multiple scientific studies that have measured reductions in CH_4 emissions from enteric fermentation.[8,9] A summary of Rumensin direct methane reduction impacts utilized within this protocol to quantify GHG reductions is highlighted in Table 2.3. These values were calculated by dividing the Rumensin effect on dietary gross energy lost as CH_4 in Model I of Table 4 in Appuhamy et al. for each respective cattle type (-0.23 for lactating and dry cows and -0.33 for replacement heifers and beef) by the average dietary gross energy lost as CH_4 for both dairy cows and beef steers (6.35%; Y_m) in Table 3 in the Appuhamy paper. Data within the Appuhamy et al. meta-analysis encompasses a wide range of productivity ranges and diets for dairy cattle. The reported milk yield from studies in the meta-analysis ranged from ~21 to 32 kg/d, giving an annual average range between 7,665 and 11,680 kg/hd/year. Diet digestible energy is not reported in all the studies, likely because this would require additional nutrient digestibility data collection which was not the focus of the trial. One study represented in the meta-analysis was a

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[7] Calculated according to equations 5.40 through 5.51

[8] Appuhamy, J.A.S.R.N. et. al. (2013). Anti-methanogenic effects of monensin in dairy and beef cattle: A meta-analysis. J. Dairy Sci. 96:5161-5173.

[9] Marumo, J. L. et al. (2023). Enteric Methane Emissions Prediction in Dairy Cattle and Effects of Monensin on Methane Emissions: A Meta-Analysis. Animals 13:(8).

pasture silage study which reported digestibility at 71.6%, which would be toward the lower end of the digestibility range based on the diets represented, so based on the diet compositions, most studies in the meta-analysis would have a DE of 70% or greater. This means the data within Appuhamy et al. encompasses the majority of the range of diets and productivity ranges within the IPCC recommendations for Ym with the exception of low producing cows (<5000 kg/head/year; DE ≤ 62; NDF > 38). However, it is a conservative approach to assume a similar 3.6% Ym reduction also applies in low producing and dry cows because dietary NDF is highly correlated with intake in dairy cows and intake is accounted for in the model used to calculate the 3.6% reduction in Ym.

For replacement heifers and beef animals retained on the dairy operation a 5.2% reduction in Ym was applied according to the beef steer data from Appuhamy et al., 2013. Beef steer data are extrapolated to replacement heifers because 1) there is no biological reason sex would alter Rumensin's mode of action, 2) the studies contributing to the data set encompass a range of high and low roughage diets, and 3) adjustments to Ym were calculated based on a model adjusting for dry matter intake which can differ across cattle types and ages.

Table 2.3 *Rumensin's impact on Ym reduction*

Animal Type	Rumensin Effect (Ym Reduction)	Reference
Lactating Cows	3.6%	Appuhamy et al., 2013
Dry Cows	3.6%	Appuhamy et al., 2013
Replacement Heifers[10]	5.2%	Appuhamy et al., 2013
Beef[11]	5.2%	Appuhamy et al., 2013

2.1.3 Rumensin Impact on Crop and Manure GHG Emissions

Due to Rumensin's effect on decreased DMI, the GHG impact of feed cultivation and manure is also reduced, providing an additional GHG benefit. These impacts are credited through the process and calculations in this protocol.

2.2 Causality

Rumensin reduces absolute emissions in the production of a consumer good along the value chain. Although Rumensin has been commercially available for almost 20 years, pressures within the industry make choosing to feed Rumensin a daily decision. Enteric methane is generated through the fermentation of feed an animal consumes at regular intervals throughout the day. Because Rumensin acts by reducing enteric methane and feed intake, the reductions in greenhouse gas emissions associated with feeding Rumensin are permanent and cannot be reversed. Each day Rumensin is not fed to an animal, 3-7% more enteric methane is released into the environment.

While financial benefits exist for producers who feed Rumensin regardless of their participation in a carbon market, there are significant barriers to Rumensin adoption or threats to the removal of Rumensin from use in dairy cattle. Premiums for organic dairy products can be 51-56% with growth rates of 7-8%[12], resulting in financial pressure to not feed Rumensin to cattle. Due to the organic market and associated public perception around antibiotic use, there is a significant threat to

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[10] All replacement heifers birth through first calving

[11] Non-replacement calves raised for beef purposes retained on the dairy operation

[12] Badruddoza, S. et al. (2022) Long-term dynamics of US organic milk, eggs, and yogurt premiums. Agribusiness 38:45-72.

removal of Rumensin's effect on reducing greenhouse gas emissions. Furthermore, many "natural" enteric methane solutions currently being evaluated also propose their methane reducing mode of action as antimicrobial.[13] It remains to be determined how different enteric methane mitigation solutions with antimicrobial modes of action are assessed and regulated.

High feed cost is another major factor which prevents Rumensin adoption or causes Rumensin removal from the diet. Although a feed additive like Rumensin with a positive effect on feed efficiency has greater returns during times of high feed cost, producers and nutritionists frequently remove it from the diet during these economically burdening times. This paradox is due to the added up-front cost to the producer and difficulty measuring farm-level return on investment to the operation due to high variability and insufficient quality of farm-level data. Variability on farms and multiple potential outcomes for the increased dietary energy gained from Rumensin (including growth, productivity, maintenance, tissue gain, and/or reduction in dry matter intake) make effects of an efficiency enhancing additive difficult to measure on-farm. Participating in a protocol and carbon credit market provides an additional benefit through financial support from the supply chain for the continued use of Rumensin. Additionally, as aforementioned, it's increasingly important that all feed additives which reduce enteric methane are considered as many producers may be incentivized to remove Rumensin from the diet to utilize carbon credit payments from "new" enteric methane reduction technologies. These replacements carry a substantial risk of mitigating less GHG emissions than currently used technologies like Rumensin. Eligibility and use of this protocol creates a data stream the supply chain will need for credibly delivering on greenhouse gas reduction commitments. This additional financial support from the supply chain for the GHG emissions reduction assures incentivizes Rumensin use and its benefits to the climate. Thus, we propose this protocol and subsequent projects be considered for quantifying and incentivizing GHG emissions reductions from feeding Rumensin.

3 Eligibility

Project shall meet all requirements listed below for this methodology to be applicable. In addition, project developers must apply the GHG SSR's, baseline scenarios and procedures to quantify, monitor, and report GHG emissions reductions as specified in this protocol.

To qualify for this protocol, Rumensin must be fed according to label instructions at the following doses by cattle type:

Dairy cattle (dry and lactating cows):

- Total Mixed Rations ("complete feed"): 11 to 22 g/ton monensin on a 100% dry matter basis.
- Component Feeding Systems (including top dress):
  - 185 to 660 mg/head/day monensin to lactating cows
  - 115 to 410 mg/head/day monensin to dry cows
  - This provides cows with similar amounts of monensin they would receive by consuming total mixed rations containing 11 to 22 g/ton monensin on a 100% dry matter basis.

Replacement heifers and beef animals:

- 200 mg per head per day

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[13] McIntosh, F. M. et al. (2003) Effects of essential oils on ruminal microorganisms and their protein metabolism. Appl. Environ. Microbiol. 69:5011–5014.

Only projects located in the U.S., or on U.S. tribal lands, are eligible to generate credits under this protocol. Projects completing a successful verification within the first year after the publication of this protocol may generate credits on operations following protocol requirements and guidelines. There is no minimum reporting period for projects developed under this protocol. The reporting period can be as short as desired by the project developer. The maximum reporting period is 12 months. After 12 months, a project may continue, but it must use the most recent version of this protocol. The reporting period is for the period of time during which the practices were implemented. Therefore, credits or reductions can be quantified as frequently as monthly and summed at the herd level.

All operations enrolled in a project are subject to a legal requirement test to ensure that the GHG reductions achieved by feeding approved practices are not required by federal, state, or local laws or regulations (e.g., air, water quality, water discharge, safety, labor, endangered species protection), or other legally binding mandates. The legal requirement test is applied to each operation enrolled in the project. Therefore, if practices at one operation in a project become legally required, it does not affect the other operations in the project.

To satisfy the legal requirement test, each producer whose operation is included in the project must sign an attestation of voluntary compliance. Attestations must be signed prior to the commencement of verification activities each time the project is verified (see Section 8). In addition, the Monitoring Plan (Section 6) must include procedures that the project developer will follow to review existing legal requirements for the project location and ascertain and demonstrate that the project operation passes the legal requirement test.

4 GHG Assessment Boundary

The GHG Assessment Boundary describes the GHG sources, sinks, and reservoirs (SSRs) that must be evaluated by project developers to determine the net change in GHG emissions resulting from the project.

The GHG Assessment Boundary encompasses the GHG SSRs that may be significantly impacted by project activities. This includes CH_4 emissions from enteric fermentation, CH_4 and nitrous oxide (N_2O) from manure management, and CO_2 and N_2O emissions from feed production (Section 5). Because the implementation of practices includes reduction in the quantity of feed provided to the cattle, leakage involving the shifting of the feed produced to other uses or other cattle operations outside the boundary of the project was evaluated, and it was concluded that leakage is not applicable to the current project because the protocol carries no risk of more than 5% reduction in crop production for any specific feed component due to the data supporting quantification of project feed cultivation GHG reductions (Table 2.2).

Figure 4.1 provides a general illustration of the GHG Assessment Boundary, indicating which SSRs are included or excluded from the boundary.

Table 4.1 provides a comprehensive list of the GHG SSRs that may be affected the project and indicates which SSRs must be included in the GHG Assessment Boundary.

Figure 4.1 *GHG Assessment Boundary*

Table 4.1 *Description of all sources, sinks, and reservoirs evaluated for the protocol*

SSR	GHG	Included or Excluded	Justification
1. Feed Cultivation	CO_2, N_2O	Included	Emissions from the transportation, production, and harvesting of cattle feed are reduced by the practices included in this protocol.
2. Enteric Fermentation	CH_4	Included	Emissions from enteric fermentation in cattle are reduced by the practices included in this protocol.
3. Manure Management	CH_4, N_2O	Included	Emissions from the management of manure are reduced by the practices included in this protocol.
4. Direct Land Use	CO_2	Excluded	Emissions from changes in land use do not change between the baseline and project scenario.
5. Fuel And Electricity Use	CO_2, N_2O, CH_4	Excluded	Fossil fuel emissions from electricity and stationary fuel use do not change between the baseline and project scenario.
6. Bedding	CO_2, CH_4, N_2O	Excluded	Emissions from the use of different bedding materials do not change between the baseline and project scenario.
7. Waste Processing	CO_2, CH_4, N_2O	Excluded	Emissions from the management of dead animals do not change between the baseline and project scenario.

5 GHG Quantification

GHG reductions from the project are quantified by comparing actual project emissions to baseline emissions. Baseline emissions are a quantification of the GHG emissions from sources within the GHG Assessment Boundary (see Section 4) that would have occurred in the absence of the project. Project emissions are the actual GHG emissions that occur at sources within the GHG Assessment Boundary during the reporting period. Project emissions must be subtracted from baseline emissions to quantify the project's total net GHG emission reductions (Equation 5.1).

$$\Delta GHG = \sum_T \quad (GHG_B^T - GHG_P^T) \qquad \text{(Equation 5.1)}$$

Where:

ΔGHG	=	Net GHG emissions from the project after implementation of the practices (kg CO$_2$e)
T	=	Type of cattle as specified in Table 5.1
GHG_B^T	=	Total GHG emissions for cattle type T from the baseline scenario (kg CO$_2$e)
GHG_P^T	=	Total GHG emissions for cattle type T from the project scenario (kg CO$_2$e)

Table 5.1 *Cattle Types*

Cattle Types
Dry Dairy Cows
Lactating Dairy Cows
Replacement Dairy Heifers, Birth To 12 Months
Replacement Dairy Heifers, 12.1 Months To Calving
Beef Animals[14]

5.1 Project GHG Emissions

Project GHG emissions are calculated according to Equation 5.2:

$$GHG_P^T = GHG_{feed,P}^T + GHG_{ent,P}^T + GHG_{man,P}^T \qquad \text{(Equation 5.2)}$$

Where:

GHG_P^T	=	Total GHG emissions for cattle type T from the project scenario (kg CO$_2$e)
$GHG_{feed,P}^T$	=	GHG emissions from the cultivation of cattle feed for cattle type T during the reporting period (kg CO$_2$e)
$GHG_{ent,P}^T$	=	GHG emissions from enteric fermentation from cattle type T during the reporting period (kg CO$_2$e)
$GHG_{man,P}^T$	=	GHG emissions from manure management for cattle type T during the reporting period (kg CO$_2$e)

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[14] Non-replacement calves raised for beef purposes retained on the dairy operation

5.1.1 Feed Cultivation

Emission factors for feed production per feed type shall be documented. If no specific emissions factors are available for a feed type, default emissions factors may be applied (e.g., based on FAO LEAP global database of GHG emissions related to feed crops[15]). Example GHG emissions from the cultivation of common feedstuffs are calculated using data from Adom et al. (2012, 2013) and Rotz et al. (2021) and are expressed according to Equations 5.3 and 5.4). Feed emissions factors should be relevant to north America, estimated using economic allocation, and include GHG emissions associated with cultivation, harvest, processing, transport, and upstream sources. Feed emissions factors will not differ between feeds grown on-farm and purchased feeds. The use of Rumensin does not appreciably affect feed emissions factors because Rumensin is included in the diet at 50 mg/kg or less, therefore the mineral and vitamin mix (of which Rumensin is often included) can be used as a proxy for Rumensin inclusion.

$$GHG^{T}_{feed,P} = \sum_{i=1}^{n} \quad EF_{feed\ i} \times DMI^{TOTAL,P}_{feed\ i}$$

(Equation 5.3)

$$DMI^{TOTAL,P}_{feed\ i} = \sum_{T} \quad (DMI^{T}_{P} \times C^{T} \times \varphi^{T}_{feed\ i} \times t)$$

(Equation 5.4)

Where:

$GHG^{T}_{feed,P}$ = GHG emissions for cattle type T from the cultivation of cattle feed during the reporting period (kg CO_2e)
$EF_{feed\ i}$ = Emissions factor (kg CO_2e per kg DM) for feed i
$DMI^{TOTAL,P}_{feed\ i}$ = Total dry matter intake of feed i to cattle type T during the reporting period (kg
DMI^{T}_{P} = Average daily dry matter intake for cattle type T during the reporting period (kg DM per head per day)
C^{T} = Number of cattle fed during the reporting period for each animal type (head)
$\varphi^{T}_{feed\ i}$ = Fractional makeup of feed i for cattle type T
t = Number of days in the reporting period (days)

Table 5.2 *Examples of common feedstuffs used for the feed emissions factors*

Feedstuff	Emissions factor (kg CO_2e kg^{-1} DM)	Reference
Alfalfa Hay	0.170	[16]
Alfalfa Silage	0.180	[16]
Beef Tallow	1.520	[17]
Canola Meal	0.500	[17]
Corn Grain	0.390	[16]
Corn Silage	0.200	[16]
Cottonseed	0.390	[18]

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[15] FAO. 2017. Global database of GHG emissions related to feed crops: A life cycle inventor https://www.fao.org/partnerships/leap/database/ghg-crops/en/

[16] Adom, F. et al. (2012). Regional carbon footprint analysis of dairy feeds for milk production in the USA. Int. J. Life Cycle Assess. 17(5):520–534.

[17] Rotz, A. et al. (2021). Environmental assessment of United States dairy farms. J. Clean. Prod. 315(June):128153.

[18] Adom, F. et al. (2013). Carbon footprint analysis of dairy feed from a mill in Michigan, USA. Int. Dairy J. 31(1):S21–S28.

Dried Distillers Grains With Soluble (DDGS), Dry Mill	0.910	[16]
Dried Distillers Grains With Soluble (DDGS), Wet Mill	0.670	[16]
Forage Mix	0.160	[16]
Grain Mix	0.550	[16]
Grass Hay	0.320	[16]
Grass Silage	0.330	[16]
Mineral And Vitamin Mix	0.162	[17]
Oats	0.850	[16]
Soybean	0.390	[16]
Soybean Meal	0.460	[16]
Winter Wheat	0.430	[16]

5.1.2 Enteric Fermentation

Project GHG emissions from enteric fermentation follow the Intergovernmental Panel on Climate Change (IPCC), 2019, Tier 2 methodology. Diet nutrient composition (i.e., DE, NDF, etc.) should be documented and calculated using feed ingredient composition weighted averages and feed values from the 2021 NASEM feed library.[19] The project emissions are calculated according to Equation 5.5:

$$GHG^{T}_{ent,P} = \sum\nolimits_{T} \quad (CH^{T}_{4\ ent,P} \times GWP_{CH_4}) \qquad \textit{(Equation 5.5)}$$

Where:

$GHG^{T}_{ent,P}$ = GHG emissions from enteric fermentation from cattle type T during the reporting period (kg CO_2e)

$CH^{T}_{4\ ent,P}$ = Methane emissions from enteric fermentation for cattle type T during the reporting period (kg CH_4)

GWP_{CH4} = 27; Global warming potential of methane (tCO_2e per tCH_4)[20]

The methane emissions generated through enteric fermentation are calculated according to Equation 5.6:

$$CH^{T}_{4\ ent,P} = EF^{T}_{CH_4\ ent,P} \times C^{T} \times t \qquad \textit{(Equation 5.6)}$$

Where:

$CH^{T}_{4\ ent,P}$ = Methane emissions from enteric fermentation for cattle type T during the reporting period (kg CH_4)

$EF^{T}_{CH_4\ ent,P}$ = Emission factor for methane of cattle type T during the reporting period (kg CH_4 per head per day)

C^{T} = Number of cattle fed during the reporting period for cattle type T type (head)

t = Number of days in the reporting period (days)

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[19] National Academies of Sciences, Engineering, and Medicine. 2021. Nutrient Requirements of Dairy Cattle: Eighth Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/25806

[20] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp.

The emission factor is calculated using Equation 5.7[21]:

$$EF^{T}_{CH_4\ ent,P} = \frac{DMI^{T}_{P} \times GE \times (\frac{Y^{T}_{m,P}}{100})}{55.65} \qquad \text{(Equation 5.7)}$$

Where:

$EF^{T}_{CH_4\ ent,P}$	=	Emission factor for methane of cattle type T during the reporting period (kg CH_4 per head per day)
DMI^{T}_{P}	=	Average daily dry matter intake for cattle type T during the reporting period (kg DM per head per day)
$Y^{T}_{m,P}$	=	Methane conversion factor during the reporting period from Methane Conversion Factor of Animals Fed Rumensin in Table 5.3 (percentage of dietary gross energy lost as CH_4)
55.65	=	Energy content of methane (MJ per kg CH_4)
GE	=	Gross energy concentration of diet (MJ per kg dry matter)

Table 5.3 *Cattle type and methane conversion factor*[22]

Cattle Type	Description	Feed quality Digestibility (DE %) and Neutral Detergent Fiber (NDF, % DMI)	2019 IPCC Methane Conversion Factor ($Y_{m,B}$)[22]	Change to Y_m with Feeding Rumensin[23]	Methane Conversion Factor of Animals Fed Rumensin ($Y_{m,P}$)
Lactating Dairy Cows	High-producing cows (>8500 kg/head/yr^{-1})	DE ≥ 70 NDF ≤ 35	5.7	-3.6%	5.49
	High-producing cows (>8500 kg/head/yr^{-1})	DE ≥ 70 NDF ≥ 35	6.0	-3.6%	5.78
	Medium producing cows (>5000 - 8500 kg/head/yr^{-1})	DE 63-70 NDF > 37	6.3	-3.6%	6.07
	Low producing cows (<5000 kg/head/yr^{-1})	DE ≤ 62 NDF > 38	6.5	-3.6%	6.27
Dry Cows			6.3[24]	-3.6%	6.07
Replacement Heifers And Beef Animals			6.3[24]	-5.2%	5.97

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[21] Equation 10.21 from Chapter 10: Emissions From Livestock and Manure Management. In 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use

[22] From Table 10.12 of Chapter 10: Emissions From Livestock and Manure Management. In 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use; used as $Y_{m,b}$ (baseline Ym) in section 5.2

[23] Appuhamy, J.A.S.R.N. et al. (2013). Anti-methanogenic effects of monensin in dairy and beef cattle: A meta-analysis. J. Dairy Sci. 96:5161-5173.

[24] A Y_m of 6.3 was used for all dry cows, replacement heifers, and beef animals based on recommendations and footnotes for non-dairy and multi-purpose cattle in Table 10.12 of Chapter 10: Emissions From Livestock and Manure Management. In 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use

The change to Ym (dietary gross energy lost as CH_4) with feeding Rumensin is calculated by dividing the Rumensin effect on dietary gross energy lost as CH_4 (intercept) in Model I of Table 4 in Appuhamy et al. (2013) for each respective cattle type by the average dietary gross energy lost as CH_4 for both dairy cows and beef steers (6.35%; Y_m) from Table 3 in the Appuhamy paper, and is calculated as:

$$\%\ change\ in\ Ym = \frac{YMI_T}{6.35} \times 100$$ (Equation 5.8)

Where:

YMI_T	=	Intercept for Rumensin effect on Ym of cattle type T[25] (percentage of dietary gross energy lost as CH_4); Model I, Table 4 of Appuhamy et al., 2013
6.35	=	Control group Ym average (percentage of dietary gross energy lost as CH_4); Table 3 of Appuhamy et al., 2013

5.1.3 Manure Management

Project GHG emissions from manure production and management are calculated according to Equations 5.9 to 5.15:

$$GHG^{T}_{man,P} = \sum_T \quad ((CH^{T}_{4\ man,P} \times GWP_{CH_4}) + (N_2O^{T}_{man,P} \times GWP_{N_2O}))$$ (Equation 5.9)

Where:

$GHG^{T}_{man,P}$	=	GHG emissions from manure management for cattle type T during the reporting period (kg CO_2e)
$CH^{T}_{4\ man,P}$	=	Methane emissions from manure production for cattle type T during the reporting period (kg CH_4)
GWP_{CH4}	=	27; Global warming potential of methane (tCO_2e per tCH_4)
$N_2O^{T}_{man,P}$	=	Nitrous oxide emissions from manure production for cattle type T during the reporting period (kg N_2O)
GWP_{N_2O}	=	273; Global warming potential of nitrous oxide (kg CO_2e per kg N_2O)[26]

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[25] "Dairy cows" intercept of -0.23 is used for dry and lactating cows, "beef steers" intercept of -0.33 is used for replacement heifers and beef animals; Beef steer data are extrapolated to replacement heifers because 1) there is no biological reason sex would alter Rumensin's mode of action, 2) the studies contributing to the data set encompass a range of high and low roughage diets, and 3) adjustments to Ym were calculated based on a model adjusting for dry matter intake which can differ across cattle types and ages.

[26] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp.

5.1.3.1 Manure Methane Emissions

Project methane emissions for the management of manure are calculated using a Tier 2 approach consistent with both IPCC and Environmental Protection Agency (EPA) quantification methodologies. It also leverages the approach used by the Climate Action Reserve's U.S. Livestock Project Protocol. Diet nutrient composition (i.e., DE, NDF, etc.) should be documented and calculated using feed ingredient composition weighted averages and feed values from the 2021 NASEM feed library.[27]

$$CH_{4\ man,P}^{T} = \sum\nolimits_{S,T} \quad (MS_{S,P}^{T}) \qquad \textit{(Equation 5.10)}$$

Where:

$CH_{4\ man,P}^{T}$	=	Methane emissions from manure production for cattle type T during the reporting period (kg CH_4)
S	=	Manure treatment system
$MS_{S,P}^{T}$	=	Methane emissions from storage/treatment system S by cattle type T, aggregated for the reporting period (kg CH_4)

$$MS_{S,P}^{T} = (C^{T} \times PS_{S,P}^{T} \times VS_{P}^{T} \times MCF_{S} \times B_{0}^{T} \times \rho_{CH_4} \times t) \qquad \textit{(Equation 5.11)}$$

Where:

$MS_{S,P}^{T}$	=	Methane emissions from storage/treatment system S by cattle type T, aggregated for the reporting period (kg CH_4)
C^{T}	=	Number of cattle fed during the reporting period for cattle type T (head)
$PS_{S,P}^{T}$	=	Percent of manure sent to (managed in) manure storage/treatment system S from cattle type T in the reporting period (%)
VS_{P}^{T}	=	Volatile solids produced by cattle type T on a dry matter basis during the reporting period (kg per head per day)
MCF_{S}	=	Methane conversion factor for storage/treatment system S from Table 5.9 (%)
B_{0}^{T}	=	Maximum methane-producing capacity of manure for cattle type T in Table 5.4 (m^3 CH_4 per kg VS)
ρ_{CH_4}	=	0.67; Density of methane = 0.67 at 1 atm and 60°F (kg per m^3)[28]

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[27] National Academies of Sciences, Engineering, and Medicine. 2021. Nutrient Requirements of Dairy Cattle: Eighth Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/25806

[28] From Equation 10.23 of Chapter 10: Emissions From Livestock and Manure Management. In 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use

$$VS_P^T = \left[(DMI_P^T \times GE) \times \left(1 - \frac{DE_P^T}{100}\right) + (UE_P^T \times [DMI_P^T \times GE])\right] \times \left[\frac{1 - ASH_P^T}{GE}\right] \quad \text{(Equation 5.12)}$$

Where:

VS_P^T = Volatile solids produced by cattle type T on a dry matter basis during the reporting period (kg per head per day)

DMI_P^T = Average daily dry matter intake for cattle type T during the reporting period (kg DM per head per day)

GE = Gross energy concentration of diet (MJ per kg dry matter)

DE_P^T = Average diet digestibility of the feed for cattle type T in the reporting period (% of gross energy)[29]

UE_P^T = 4%; Urinary energy as a percent of gross energy of cattle type T in the reporting period (%)[30]

ASH_P^T = 8%; Ash content of feed for cattle type T in the reporting period (%)[30,31]

Table 5.4 *Maximum methane producing capacity of manure for cattle*[32]

Cattle Types (T)	$B_0{}^T$ (m^3 CH_4 kg^{-1} VS)
Dry And Lactating Dairy Cows	0.24
Replacement Dairy Heifers	0.19
Beef Animals	0.19

5.1.3.2 Manure Nitrous Oxide Emissions

Manure nitrous oxide emissions are calculated according to IPCC and the guidance of IDF, 2020 which includes a minimum requirement of “direct and indirect N_2O emissions from excreta in cattle housing, storage and treatment.”[33] Co-digestate values are not affected by project implementation and are not included in calculations. Project emissions of N_2O are calculated as follows:

$$N_2O_{man,P}^T = \sum_T \quad (N_2O_{d,P}^T + N_2O_{i,l,P}^T + N_2O_{i,v,P}^T) \quad \text{(Equation 5.13)}$$

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[29] Diet digestibility calculated using values from National Academies of Sciences, Engineering, and Medicine. 2021. Nutrient Requirements of Dairy Cattle: Eighth Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/25806

[30] From Equation 10.24 of Chapter 10: Emissions From Livestock and Manure Management. In 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use

[31] Dämmgen U. et al. (2011). Reassessment of the calculation procedure for the volatile solids excretion rates of cattle and pigs in the Austrian, Danish and German agricultural emission inventories. Landbauforschung Volkenrode 61:115-126.

[32] From Table 10.16 of Chapter 10: Emissions From Livestock and Manure Management. In 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4: Agriculture, Forestry and Other Land Use

[33] IDF. 2022. The IDF global Carbon Footprint standard for the dairy sector. In: Bulletin of the IDF No. 520/2022. International Dairy Federation (ed.), Brussels.

Where:

$N_2O^T_{man,P}$ = Nitrous oxide emissions from manure production for cattle type T during the reporting period (kg N_2O)

$N_2O^T_{d,P}$ = Direct N_2O emissions from manure management for cattle type T during the reporting period (kg N_2O)

$N_2O^T_{i,l,P}$ = Indirect N_2O emissions from leaching of manure for cattle type T during the reporting period (kg N_2O)

$N_2O^T_{i,v,P}$ = Indirect N_2O emissions from the volatilization of NH_3 and NO_x for cattle type T during the reporting period (kg N_2O)

5.1.3.2.1 Direct N₂O Emissions from Manure Management

The calculation of direct N_2O emissions entails multiplying the total amount of nitrogen excretion in each type of manure management system by an emission factor for that type of system and summing the obtained values. The emissions are then calculated using Equations 5.14 and 5.15:

$$N_2O^T_{d,P} = \left(\sum_S \quad N^T_{S,P}\right) \times EF_{d,S} \times \frac{44}{28} \qquad \text{(Equation 5.14)}$$

$$N^T_{S,P} = \left(N^T_{ex,P} \times PS^T_{S,P}\right) \qquad \text{(Equation 5.15)}$$

Where:

$N_2O^T_{d,P}$ = Direct N_2O emissions from manure management for cattle type T during the reporting period (kg N_2O)

$N^T_{S,P}$ = Total nitrogen from cattle type T managed by storage system S during the reporting period (kg N)

$EF_{d,S}$ = Emissions factor for direct N_2O emissions from the manure management system S in Table 5.5 (kg N_2O-N per kg N excreted)

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

$N^T_{ex,P}$ = N excretion by cattle type T, aggregated for the reporting period (kg N)

$PS^T_{S,P}$ = Percent of manure sent to (managed in) manure storage/treatment system S from cattle type T in the reporting period (%)

***Table 5.5** Default emission factors for direct N2O Emission from manure management*[34]

System	Definition		$EF_{d,S}$ [kg N_2O-N (kg N excreted)$^{-1}$]
Pasture/Range/ Paddock	The manure from pasture and range grazing animals is allowed to lie as is and is not managed.		Direct and indirect N_2O emissions associated with the manure deposited on agricultural soils and pasture, range, and paddock systems are not included in this protocol.
Daily Spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion. N_2O emissions during storage and treatment are assumed to be zero. N_2O emissions from land application are covered under the Agricultural Soils category.		0
Solid Storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.		0.010
Solid Storage – Covered/Compacted	Similar to solid storage, but the manure pile is a) covered with a plastic sheet to reduce the surface of manure exposed to air and/or b) compacted to increase the density and reduce the free air space within the material.		0.01
Solid Storage – Bulking Agent Addition	Specific materials (bulking agents) are mixed with the manure to provide structural support. This allows the natural aeration of the pile, thus enhancing decomposition. (e.g. sawdust, straw, coffee husks, maize stover)		0.005
Solid Storage – Additives	The addition of specific substances to the pile in order to reduce gaseous emissions. Addition of certain compounds such as attapulgite, dicyandiamide or mature compost have shown to reduce N_2O emissions; while phosphogypsum reduce CH_4 emission		0.005
Dry Lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically. Dry lots are most typically found in dry climates but also are used in humid climates.		0.02
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water to facilitate handling and is stored in either tanks or earthen ponds.	With natural crust cover	0.005
		Without natural crust cover	0
		Cover	0.005
Uncovered Anaerobic Lagoon	Anaerobic lagoons are designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilize fields.		0

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[34] Adapted from Table 10.21 of 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Pit Storage Below Animal Confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility.		0.002
Anaerobic Digester	Anaerobic digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CH_4 and CO_2, which is captured and flared or used as a fuel.		0.0006
Deep Bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.	No mixing	0.01
		Active mixing	0.07
Composting – In-Vessel	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.		0.006
Composting – Static Pile (Forced Aeration)	Composting in piles with forced aeration but no mixing.		0.010
Composting – Intensive Windrow (Frequent Turning)	Composting in windrows with regular turning for mixing and aeration.		0.005
Composting – Passive Windrow (Infrequent Turning)	Composting in windrows with infrequent turning for mixing and aeration.		0.005
Aerobic Treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration. Natural aeration is limited to aerobic and facultative ponds and wetland systems and is due primarily to photosynthesis. Hence, these systems typically become anoxic during periods without sunlight.	Natural aeration systems	0.01
		Forced aeration systems	0.005

Nitrogen intake is used to determine N excretion in equations 5.17 and 5.19 and is calculated for all cattle types according to Equation 5.16[35]:

$$N_{i,P}^{T} = DMI_{P}^{T} \times \frac{\frac{CP^{T}}{100}}{6.25} \qquad \text{(Equation 5.16)}$$

Where:

$N_{i,P}^{T}$ = Nitrogen intake for cattle type T during the reporting period (kg per head per day)

DMI_{P}^{T} = Average daily dry matter intake for cattle type T during the reporting period (kg DM per head per day)

CP^{T} = Crude protein content in the diet for cattle type T (%)[36]

6.25 = Conversion from kg of dietary protein to kg of dietary N (kg feed protein per kg N)

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[35] Equation 10.32 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[36] From NASEM, 2021. Nutrient Requirements of Dairy Cattle: Eighth Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/25806

Rate of N excretion for lactating cows is calculated according to the following equation[37]:

$$N_{ex,P}^{T} = (N_{i,P}^{T} - N_{R,P}^{T}) \times C^{T} \times t \qquad \textit{(Equation 5.17)}$$

Where:

$N_{ex,P}^{T}$	=	N excretion by cattle type T, aggregated for the reporting period (kg N)
$N_{i,P}^{T}$	=	Nitrogen intake for cattle type T during the reporting period (kg per head per day)
$N_{R,P}^{T}$	=	N retained by lactating animals. Calculated according to equation 5.18 (kg per head per day)[39]
C^{T}	=	Number of cattle fed during the reporting period for cattle type T(head)
t	=	Number of days in the reporting period (days)

Nitrogen retained by lactating animals is calculated according to Equation 5.18[38]:

$$N_{R,P}^{T} = \left[\frac{M \times \left(\frac{M_p}{100}\right)}{6.38}\right] + \left[\frac{WG \times \frac{\left[268 - \left(\frac{7.03 \times NE_G}{WG}\right)\right]}{1000}}{6.25}\right] \qquad \textit{(Equation 5.18)}$$

Where:

$N_{R,P}^{T}$	=	N retained by lactating animal during the reporting period (kg per head per day)[39]
M	=	Milk production (kg per head per day)
M_p	=	Percent of protein in the milk (%)
6.38	=	Conversion from milk protein to milk N (kg protein per kg N)[39]
WG	=	Weight gain; 0 for mature lactating cattle[40]
NE_G	=	Net energy for growth (MJ/d); not applicable for lactating mature lactating cattle because weight gain = 0[40]

Rate of N excretion for all other cattle types (dry, replacement heifers, and beef) is calculated according to Equation 5.19[41]:

$$N_{ex,P}^{T} = N_{i,P}^{T} \times \left(1 - N_{R\_frac}^{T}\right) \times C^{T} \times t \qquad \textit{(Equation 5.19)}$$

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[37] Equation 10.31A in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[38] Equation 10.33 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[39] Equation 10.33 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[40] Table 10A.1 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[41] Equation 10.31 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Where:

$N_{ex,P}^{T}$ = N excretion by cattle type T, aggregated for the reporting period (kg N)

$N_{i,P}^{T}$ = Nitrogen intake for cattle type T during the reporting period (kg per head per day)

$N_{R\_frac}^{T}$ = N retention fraction in non-lactating cattle types from Table 5.6 (kg N retained per head per day per kg N intake per head per day)

C^T = Number of cattle fed during the reporting period for cattle type T (head)

t = Number of days in the reporting period (days)

Table 5.6 *Data for estimating N retention fractions for various cattle types*[42]

Animal Type	Fraction N Retained (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$
Dry Cows	0.07
Heifers 0-12 Months	0.16
Heifers 12.1 Months To First Calving	0.14
Beef	0.14

5.1.3.2.2 Indirect N$_2$O Emissions from Leaching of Manure

Nitrogen is lost through runoff and leaching into soils from the solid storage of manure at outdoor areas and in feedlots. The amount of nitrous oxide emitted through leaching shall be calculated using Equation 5.20:

$$N_2O_{i,l,P}^{T} = \sum_S \quad (N_{S,P}^{T} \times Frac_{leach\_MS_S}{}^{T}) \times EF_5 \times \frac{44}{28} \qquad \textit{(Equation 5.20)}$$

Where:

$N_2O_{i,l,P}^{T}$ = Indirect N_2O emissions from leaching of manure for cattle type T during the reporting period (kg N_2O)

$N_{S,P}^{T}$ = Total nitrogen from cattle type T managed by storage system S during the reporting period (kg N)

$Frac_{leach\_MS_S}{}^{T}$ = Fraction of managed manure nitrogen losses for cattle type T due to runoff and leaching during solid and liquid storage of manure in manure management system S from Table 5.7.

EF_5 = Emission factor for N_2O emissions from nitrogen leaching and runoff from Table 5.8 (kg N_2O-N per kg N leached and runoff)

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

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[42] Table 10A.2 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

5.1.3.2.3 Indirect N2O Emissions from Volatilization of NH_3 and NO_x

Nitrogen in the volatilized form of ammonia may be deposited at sites downwind from manure handling areas and contribute to indirect N_2O emissions. The amount of nitrous oxide emitted through volatilization in the forms of NH_3 and NO_x is calculated using Equation 5.21:

$$N_2O^T_{i,v,P} = \sum_S \quad (N^T_{S,P} \times Frac_{Gas\_MS}{}^T_S) \times EF_4 \times \frac{44}{28} \qquad \text{(Equation 5.21)}$$

Where:

$N_2O^T_{i,v,P}$ = Indirect N_2O emissions from the volatilization of NH_3 and NO_x for cattle type T during the reporting period (kg N_2O)

$N^T_{S,P}$ = Total nitrogen from cattle type T managed by storage system S during the reporting period (kg N)

$Frac_{Gas\_MS}{}^T_S$ = Fraction of managed manure nitrogen for livestock type T that volatilizes as NH_3 and NO_x in the manure management system S from Table 5.7.

EF_4 = Emission factor for N_2O emissions from nitrogen volatilization from Table 5.8 (kg N_2O-N per kg NH_3-N + NO_x-N volatilized)

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

Table 5.7 *Default values for N loss fractions due to volatilization of NH3 and NOx and leaching of N from manure management*[43]

System	$Frac_{leach\_MS}$	$Frac_{Gas\_MS}$
Uncovered Anaerobic Lagoon	0	0.35
Liquid/Slurry - With Natural Crust Cover	0	0.30
Liquid/Slurry - Without Natural Crust Cover	0	0.48
Liquid/Slurry - With Cover	0	0.10
Pit Storage Below Animal Confinements	0	0.28
Daily Spread	0	0.07
Solid Storage	0.02	0.30
Solid Storage - Covered/Compacted	0	0.14
Solid Storage - Bulking Agent Addition	0.02	0.38
Solid Storage - Additives	0.02	0.11
Dry Lot	0.035	0.30
Anaerobic Digester	0	0.05-0.50
Cattle And Swine Deep Bedding	0.035	0.25
Composting - In-Vessel	0	0.45
Composting - Static Pile	0.06	0.50
Composting - Intensive Windrow	0.06	0.50
Composting - Passive Windrow	0.04	0.45
Aerobic Treatment - Natural Aeration Systems	0	No data
Aerobic Treatment - Forced Aeration Systems	0	0.85

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[43] From Table 10.22 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Table 5.8 *Default emission volatilization and leaching factors used for indirect soil N2O emissions*[44]

Climate	EF$_4$, kg N_2O-N (kg NH_3-N + NO_x-N volatilized)$^{-1}$	EF$_5$, kg N_2O-N/kg N leached and runoff
Cool Temperate Moist	0.014	0.011
Cool Temperate Dry	0.005	0.011
Boreal Moist	0.014	0.011
Boreal Dry	0.005	0.011
Warm Temperate Moist	0.014	0.011
Warm Temperate Dry	0.005	0.011
Tropical Montane	0.014	0.011
Tropical Wet	0.014	0.011
Tropical Moist	0.014	0.011
Tropical Dry	0.005	0.011

Table 5.9 *Methane conversion factor (MCF) for manure management systems*[45]

System		MCFs by Climate Zone									
		Cool				Temperate		Warm			
		Cool Temperate Moist	Cool Temperate Dry	Boreal Moist	Boreal Dry	Warm Temperate Moist	Warm Temperate Dry	Tropical Montane	Tropical Wet	Tropical Moist	Tropical Dry
Uncovered Anaerobic Lagoon		60%	67%	50%	49%	73%	76%	76%	80%	80%	80%
Liquid/Slurry, And Pit Storage Below Animal Confinements	1 Month	6%	8%	4%	4%	13%	15%	25%	38%	36%	42%
	3 Month	12%	16%	8%	8%	24%	28%	43%	61%	57%	62%
	4 Month	15%	19%	9%	9%	29%	32%	50%	67%	64%	68%
	6 Month	21%	26%	14%	14%	37%	41%	59%	76%	73%	74%
	12 Month	31%	42%	21%	20%	55%	64%	73%	80%	80%	80%
Cattle And Swine Deep Bedding (Cont.)	> 1 Month	21%	26%	14%	14%	37%	41%	59%	76%	73%	74%
Cattle And Swine Deep Bedding	< 1 Month	2.75%				6.50%		18%			
Solid Storage		2.00%				4.00%		5.00%			
Solid Storage – Covered/Compacted		2.00%				4.00%		5.00%			
Solid Storage – Bulking Agent Addition		0.50%				1.00%		1.50%			
Solid Storage – Additives		1.00%				2.00%		2.50%			
Dry Lot		1.00%				1.50%		2.00%			
Daily Spread		0.10%				0.50%		1.00%			

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[44] From Table 11.3 in Chapter 11 of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[45] Adapted from Table 10.17 of 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

System	MCFs by Climate Zone									
	Cool				Temperate		Warm			
	Cool Temperate Moist	Cool Temperate Dry	Boreal Moist	Boreal Dry	Warm Temperate Moist	Warm Temperate Dry	Tropical Montane	Tropical Wet	Tropical Moist	Tropical Dry
Composting – In-Vessel	0.50%									
Composting – Static Pile (Forced Aeration)	1.00%				2.00%		2.50%			
Composting – Intensive Windrow	0.50%				1.00%		1.5%			
Composting – Passive Windrow (Infrequent Turning)	1.00%				2.00%		2.50%			
Pasture/Range/Paddock	0.47%									
Poultry Manure With And Without Litter	1.50%									
Aerobic Treatment	0.00%									
Burned For Fuel	10.00%									
Anaerobic Digester, Low Leakage, High Quality Gastight Storage, Best Complete Industrial Technology	1.00%									
Anaerobic Digester, Low Leakage, High Quality Industrial Technology, Low Quality Gastight Storage Technology	1.41%									
Anaerobic Digester, Low Leakage, High Quality Industrial Technology, Open Storage	3.55%				4.38%		4.59%			
Anaerobic Digester, High Leakage, Low Quality Technology, High Quality Gastight Storage Technology	9.59%									
Anaerobic Digester, High Leakage, Low Quality Technology, Low Quality Gastight Storage Technology	10.85%									
Anaerobic Digester, High Leakage, Low Quality Technology, Open Storage	12.14%				12.97%		13.17%			

5.2 Baseline GHG Emissions

Baseline emissions are calculated using Equation 5.22 through 5.39 and the adjustment factors in Table 5.10.

Equation	Equation #	Description
$GHG_B^T = GHG_{feed,B}^T + GHG_{ent,B}^T + GHG_{man,B}^T$	(Equation 5.22)	Total GHG emissions for cattle type T in the baseline scenario (kg CO2e)
$GHG_{feed,B}^T = \sum_{i=1}^{n} \quad EF_{feed\ i} \times \left(\frac{DMI_{feed\ i}^{TOTAL,P}}{AF_{DMI}^T}\right)$	(Equation 5.23)	GHG emissions from the cultivation of cattle feed for cattle type T in the baseline scenario (kg CO_2e)
$GHG_{ent,B}^T = \sum_T \quad (CH_{4\ ent,B}^T \times GWP_{CH_4})$	(Equation 5.24)	GHG emissions from enteric fermentation from cattle type T in the baseline scenario (kg CO_2e)
$CH_{4\ ent,B}^T = EF_{CH_4\ ent,B}^T \times C^T \times t$	(Equation 5.25)	Methane emissions from enteric fermentation for cattle type T in the baseline scenario (kg CH_4)
$EF_{CH_4\ ent,B}^T = \frac{\left(\frac{DMI_P^T}{AF_{DMI}^T}\right) \times GE \times \left(\frac{Y_{m,B}^T}{100}\right)}{55.65}$	(Equation 5.26)	Emission factor for methane of cattle type T in the baseline scenario (kg CH_4 per head per day)
$GHG_{man,B}^T = \sum_T \quad ((CH_{4\ man,B}^T \times GWP_{CH_4}) + (N_2O_{man,B}^T \times GWP_{N_2O}))$	(Equation 5.27)	GHG emissions from manure management for cattle type T in the baseline scenario (kg CO_2e)
$CH_{4\ man,B}^T = \sum_{S,T} \quad (MS_{S,B}^T)$	(Equation 5.28)	Methane emissions from manure production for cattle type T in the baseline scenario (kg CH_4)
$MS_{S,B}^T = (C^T \times PS_{S,P}^T \times VS_B^T \times MCF_S \times B_0^T \times \rho_{CH_4} \times t)$	(Equation 5.29)	Methane emissions from storage/treatment system S by cattle type T in the baseline scenario (kg CH_4)
$VS_B^T = \left[\left(\frac{DMI_P^T}{AF_{DMI}^T}\right) \times GE\right] \times \left(1 - \frac{DE_P^T}{100}\right) + \left(UE_P^T \times \left[\left(\frac{DMI_P^T}{AF_{DMI}^T}\right) \times GE\right]\right) \times \left[\left(\frac{1-ASH_P^T}{GE}\right)\right]$	(Equation 5.30)	Volatile solids produced by cattle type T on a dry matter basis in the baseline scenario (kg per head per day)
$N_2O_{man,B}^T = \sum_T \quad (N_2O_{d,B}^T + N_2O_{i,l,B}^T + N_2O_{i,v,B}^T)$	(Equation 5.31)	Nitrous oxide emissions from manure production for cattle type T in the baseline scenario (kg N_2O)
$N_2O_{d,B}^T = (\sum_S \quad N_{S,B}^T) \times EF_{d,S} \times \frac{44}{28}$	(Equation 5.32)	Direct N_2O emissions from manure management for cattle type T in the baseline scenario (kg N_2O)
$N_2O_{i,l,B}^T = \sum_S \quad (N_{S,B}^T \times Frac_{leach\_MS_S}{}^T) \times EF_5 \times \frac{44}{28}$	(Equation 5.33)	Indirect N_2O emissions from leaching of manure for cattle type T in the baseline scenario (kg N_2O)
$N_2O_{i,v,B}^T = \sum_S \quad (N_{S,B}^T \times Frac_{Gas\_MS_S}{}^T) \times EF_4 \times \frac{44}{28}$	(Equation 5.34)	Indirect N_2O emissions from the volatilization of NH_3 and NO_x for cattle type T in the baseline scenario (kg N_2O)

$N_{S,B}^{T} = (N_{ex,B}^{T} \times PS_{S,P}^{T})$	(Equation 5.35)	Total nitrogen from cattle type T managed by storage system S in the baseline scenario (kg N)
$N_{ex,B}^{T} = (N_{i,B}^{T} - N_{R,B}^{T}) \times C^{T} \times t$	(Equation 5.36)	N excretion for lactating cattle type aggregated in the baseline scenario (kg N)
$N_{ex,B}^{T} = N_{i,B}^{T} \times \left(1 - N_{R\_frac}^{T}\right) \times C^{T} \times t$	(Equation 5.37)	N excretion by non-lactating cattle types aggregated in the baseline scenario (kg N)
$N_{R,B}^{T} = \left[\frac{\frac{M}{AF_{M}^{T}} \times \left(\frac{M_p}{100}\right)}{6.38}\right] + \left[\frac{WG \times \frac{\left[268 - \left(\frac{7.03 \times NE_G}{WG}\right)\right]}{1000}}{6.25}\right]$	(Equation 5.38)	N retained by lactating animal in the baseline scenario (kg per head per day)
$N_{i,B}^{T} = \left(\frac{DMI_{P}^{T}}{AF_{DMI}^{T}}\right) \times \left[\frac{\left(\frac{CP^{T}}{100}\right)}{6.25}\right]$	(Equation 5.39)	Nitrogen intake for cattle type T in the baseline scenario (kg per head per day)

Where:

GHG_{B}^{T} = Total GHG emissions for cattle type T from the baseline scenario (kg CO_2e)

$GHG_{feed,B}^{T}$ = GHG emissions for cattle type T from the cultivation of cattle feed in the baseline scenario (kg CO_2e)

$GHG_{ent,B}^{T}$ = GHG emissions from enteric fermentation from cattle type T in the baseline scenario (kg CO_2e)

$GHG_{man,B}^{T}$ = GHG emissions from manure management for cattle type T in the baseline scenario (kg CO_2e)

$EF_{feed\ i}$ = Emissions factor (kg CO_2e per kg DM) for feed i

$DMI_{feed\ i}^{TOTAL,P}$ = Total dry matter intake of feed i to cattle type T during the reporting period (kg)

AF_{DMI}^{T} = Dry matter intake adjustment factor for cattle type T from Table 5.10

$CH_{4\ ent,B}^{T}$ = Methane emissions from enteric fermentation for cattle type T in the baseline scenario (kg CH_4)

GWP_{CH4} = 27; Global warming potential of methane (tCO_2e per tCH_4)

$CH_{4\ ent,B}^{T}$ = Methane emissions from enteric fermentation for cattle type T in the baseline scenario (kg CH_4)

$EF_{CH_4\ ent,B}^{T}$ = Emission factor for methane of cattle type T in the baseline scenario (kg CH_4 per head per day)

C^T = Number of cattle fed during the reporting period for each animal type (head)

t = Number of days in the reporting period (days)

DMI_{P}^{T} = Average daily dry matter intake for cattle type T during the reporting period (kg DM per head per day)

$Y_{m,B}^{T}$ = Methane conversion factor in the baseline scenario in Table 5.3 (percentage of dietary gross energy lost as CH_4)

55.65 = Energy content of methane (MJ per kg CH_4)

GE = Gross energy concentration of diet (MJ per kg dry matter)

$CH_{4\ man,B}^{T}$ = Methane emissions from manure production for cattle type T in the baseline scenario (kg CH_4)

$N_2O_{man,B}^{T}$ = Nitrous oxide emissions from manure production for cattle type T in the baseline scenario (kg N_2O)

GWP_{N_2O} = 273; Global warming potential of nitrous oxide (kg CO2e kg N_2O^{-1})

$MS_{S,B}^{T}$ = Methane emissions from storage/treatment system S by cattle type T in the baseline scenario (kg CH_4)

$PS_{S,P}^{T}$ = Percent of manure sent to (managed in) manure storage/treatment system S from cattle type T in the reporting period (%)

VS_{B}^{T} = Volatile solids produced by cattle type T on a dry matter basis in the baseline scenario (kg per head per day)

MCF_{S} = Methane conversion factor for storage/treatment system S from Table 5.9 (%)

B_{0}^{T} = Maximum methane-producing capacity of manure for cattle type T in Table 5.5 (m^3 CH_4 per kg VS)

ρ_{CH_4} = 0.67; Density of methane = 0.67 at 1 atm and 60°F (kg per m^3)

DE_{P}^{T} = Average diet digestibility of the feed for cattle type T in the reporting period (% of gross energy)

UE_{P}^{T} = 4%; Urinary energy as a percent of gross energy of cattle type T in the reporting period (%)

ASH_{P}^{T} = 8%; Ash content of feed for cattle type T in the reporting period (%)

$N_2O_{d,B}^{T}$ = Direct N_2O emissions from manure management for cattle type T in the baseline scenario (kg N_2O)

$N_2O_{i,l,B}^{T}$ = Indirect N_2O emissions from leaching of manure for cattle type T during in the baseline scenario (kg N_2O)

$N_2O_{i,v,B}^{T}$ = Indirect N_2O emissions from the volatilization of NH_3 and NO_x for cattle type T in the baseline scenario (kg N_2O)

$N_{S,B}^{T}$ = Total nitrogen from cattle type T managed by storage system S in the baseline scenario period (kg N)

$EF_{d,S}$ = Emissions factor for direct N_2O emissions from the manure management system S in Table 5.5 (kg N_2O-N per kg N excreted)

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

$Frac_{leach\_MS_S}^{\;T}$ = Fraction of managed manure nitrogen losses for cattle type T due to runoff and leaching during solid and liquid storage of manure in manure management system S from Table 5.7.

EF_5 = Emission factor for N_2O emissions from nitrogen leaching and runoff from Table 5.8 (kg N_2O-N per kg N leached and runoff)

$Frac_{Gas\_MS_S}^{\;T}$ = Fraction of managed manure nitrogen for livestock type T that volatilizes as NH_3 and NO_x in the manure management system S from Table 5.7.

EF_4 = Emission factor for N_2O emissions from nitrogen volatilization from Table 5.8 (kg N_2O-N per kg NH_3-N + NO_x-N volatilized)

$N_{ex,B}^{T}$ N excretion for cattle type T aggregated in the baseline scenario (kg N)

$N_{i,B}^{T}$ = Nitrogen intake for cattle type T in the baseline scenario (kg per head per day)

$N_{R,B}^{T}$ N retained by lactating dairy cow type through milk in the baseline scenario (kg per head per day)[39]

$N_{R\_frac}^{T}$ = N retention fraction in non-lactating cattle types from Table 5.6 (kg N retained per head per day per kg N intake per head per day)

M = Milk production during the reporting period (kg per head per day)

M_p = Percent of protein in the milk (%)

6.38 = Conversion from milk protein to milk N (kg protein per kg N)

AF_M^T = Milk yield adjustment factor for lactating cows from table 5.10

WG = Weight gain; 0 for mature lactating cattle[46]

NE_G = Net energy for growth (MJ/d); not applicable for lactating mature lactating cattle because weight gain = 0[46]

CP^T = Crude protein content in the diet for cattle type T (%)

6.25 = Conversion from kg of dietary protein to kg of dietary N (kg feed protein per kg N)

Table 5.10 *Baseline adjustment factors*

Adjustment Factor	Cattle Type	Value	Reference
$\boldsymbol{AF_{DMI}^T}$	Dry Dairy Cows	0.977	Duffield et al., 2008
$\boldsymbol{AF_{DMI}^T}$	Lactating Dairy Cows	0.977	Duffield et al., 2008
$\boldsymbol{AF_{DMI}^T}$	Replacement Dairy Heifers, 12.1 Months Old To Calving	0.957	Gadberry et al., 2022
$\boldsymbol{AF_M^T}$	Lactating Dairy Cows	1.005	Duffield et al., 2008

The baseline adjustment factor for dry matter intake is calculated according to Equation 5.40:

$$AF_{DMI}^T = 1 - \left|\frac{DM\_change_T}{100}\right| \qquad \text{(Equation 5.40)}$$

Where:

AF_{DMI}^T = Dry matter intake adjustment factor for cattle type T

DM_change_T = Change in dry matter intake in cattle type T due to Rumensin (%)[47]

Because significant heterogeneity was observed with milk components, the reported yield and component percentages reported in Table 2 of Duffield et al., 2008 were used to calculate solids-corrected milk (SCM) differences between control and Rumensin treatments according to Vasquez et al. (2021)[48], resulting in a 0.5% increase in SCM with Rumensin. This 0.5% increase was utilized for Rumensin's effect on milk yield. The adjustment factor for milk yield is calculated according to Equation 5.41:

$$AF_M^T = 1 + \left|\frac{SCM_R - SCM_C}{SCM_C}\right| \qquad \text{(Equation 5.41)}$$

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[46] Table 10A.1 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

[47] Values from Table 2 in Duffield et al., 2008 for dry and lactating cows and page 4 of Gadberry et al., 2022 for replacement dairy heifers, 12.1 months old to calving

[48] Vasquez et al., 2021 Table 5 footnote 2

Where:

AF_M^T = Milk yield adjustment factor for lactating cows

SCM_R = Solids-corrected milk in Rumensin cows (kg/d)

SCM_C = Solids-corrected milk in control cows (kg/d)

Solids corrected milk in control cows is calculated according to Equation 5.42[48]:

$$SCM_C = MY_C \times [(12.24 \times fat\%_C \times 0.01) + (7.1 \times protein\%_C \times 0.01) + (6.35 \times lactose\%_C \times 0.01) - 0.0345] \quad \text{(Equation 5.42)}$$

Values for control milk yield (kg/d), fat %, protein %, and lactose % are calculated by dividing the raw weighted mean difference (Rumensin – control) by the percent change[49] from Duffield et al. (2008) according to the following equations:

$$MY_C = \frac{MY\_dif}{MY\_change} \quad \text{(Equation 5.43)}$$

$$fat\%_C = \frac{fat\%\_dif}{fat\%\_change} \quad \text{(Equation 5.44)}$$

$$protein\%_C = \frac{protein\%\_dif}{protein\%\_change} \quad \text{(Equation 5.45)}$$

$$lactose\%_C = \frac{lactose\%\_dif}{lactose\%\_change} \quad \text{(Equation 5.46)}$$

Where:

SCM_C = Solids-corrected milk in control cows (kg/d)

MY_C = Control milk yield (kg/d)

$fat\%_C$ = Control milk fat (%)

$protein\%_C$ = Control milk protein (%)

$lactose\%_C$ = Control milk lactose (%)

MY_dif = Milk yield, raw weighted mean difference; 0.7 kg/d[49]

MY_change = Milk yield, percent change; 2.3%[49]

$fat\%\_dif$ = Milk fat percent, raw weighted mean difference; -0.12[49]

$fat\%\_change$ = Milk fat percent, percent change; -3.1%[49]

$protein\%\_dif$ = Milk protein percent, raw weighted mean difference; -0.03[49]

$protein\%\_change$ = Milk protein percent, percent change; -0.9%[49]

$lactose\%\_dif$ = Milk lactose percent, raw weighted mean difference; -0.012[49]

$lactose\%\_change$ = Milk lactose percent, percent change; -0.25%[49]

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[49] Values for both raw weighted mean difference of Rumensin – control and percent change are reported in Table 2 of Duffield et al., 2008

Solids corrected milk in Rumensin cows is calculated according to the following equation[48]:

$$SCM_R = MY_C \times [(12.24\ \times fat\%_R\ \times 0.01) + (7.1\ \times protein\%_R\ \times 0.01) + (6.35\ \times lactose\%_R\ \times 0.01) - 0.0345] \qquad \text{(Equation 5.47)}$$

Values for Rumensin milk yield (kg/d), fat %, protein %, and lactose % are calculated by adding raw weighted mean differences from Table 5.11 from the calculated control values according to the following equations:

$$MY_R = MY_C + MY\_dif \qquad \text{(Equation 5.48)}$$

$$fat\%_R = fat\%_C + fat\%\_dif \qquad \text{(Equation 5.49)}$$

$$protein\%_R = protein\%_C + protein\%\_dif \qquad \text{(Equation 5.50)}$$

$$lactose\%_R = lactose\%_C + lactose\%\_dif \qquad \text{(Equation 5.51)}$$

Where:

MY_R = Rumensin milk yield (kg/d)
MY_C = Control milk yield (kg/d)
MY_dif = Milk yield, raw weighted mean difference; 0.7 kg/d
$fat\%_C$ = Control milk fat (%)
$protein\%_C$ = Control milk protein (%)
$lactose\%_C$ = Control milk lactose (%)
$fat\%_R$ = Rumensin milk fat (%)
$protein\%_R$ = Rumensin milk protein (%)
$lactose\%_R$ = Rumensin milk lactose (%)
$fat\%\_dif$ = Milk fat percent, raw weighted mean difference; -0.12[49]
$protein\%\_dif$ = Milk protein percent, raw weighted mean difference; -0.03[49]
$lactose\%\_dif$ = Milk lactose percent, raw weighted mean difference; -0.012[49]

5.3 Leakage

During the development of this protocol, the need to account for market-shifting leakage associated with reductions in feed to cattle was evaluated. The principle of leakage suggests that the reduction in feed due to project implementation will be moved to other uses and the associated GHG emissions are shifted, not eliminated. The current project carries no risk of more than 5% reduction in crop production for any specific feed component due to the data supporting quantification of project feed cultivation GHG reductions. The effect of project implementation on dry matter intake reductions used for GHG reduction quantifications are stated in Tables 2.1 (effect of Rumensin on each parameter) and 5.11 (adjustment factors on project emissions [i.e., during feeding Rumensin] to calculate baseline values). Because the maximum reduction in feed production within this protocol is less than 5%, leakage is not relevant to this project and no deductions will be applied to credits generated according to this protocol.

5.4 Uncertainty

Traditionally a large amount of uncertainty in dairy operation greenhouse gas calculations originates from estimations of feed intake and digestibility, which vary widely between and within cattle and geographies. A significant portion of this uncertainty is mitigated in this protocol through utilizing each project's individual feed ingredient data to quantify dry matter intake and more accurately estimate gross and digestible energy. The availability of these data facilitates a precise measure of gross energy intake by cattle type from which feed cultivation, enteric, and manure emissions reductions are calculated. Because feed intake is recorded and received directly from the dairy farm, the remaining uncertainty associated with the GHG reductions quantified in this protocol arise from the adjustments made around the intervention of Rumensin implementation. These adjustments are taken directly from reputable and peer-reviewed meta-analyses. Rumensin has reliable and substantiated data regarding its mode of action and effect, and a summary of reported error associated with these effects is reported in Table 5.11. The error across the reported means that are used to calculate adjustment factors throughout this protocol averages approximately 41% of the mean.

Because uncertainty associated with feed intake, a primary driver in GHG emissions, was mitigated through incorporating project-specific feed data in a tier 2 approach to calculate GHG emissions and uncertainty associated with adjustment factors for Rumensin's effect were mitigated using meta-analyses, no deductions for uncertainty will be taken.

Table 5.11 *Reported error values around Rumensin effects*

	Reported Mean Rumensin Effect	Error Value Reported	Error Metric	Approximate Error as % of the Mean	Reference
Dairy Ym Effect, percentage points	-0.23	0.14	Standard Error	61%	Appuhamy et al., 2013
Replacement Heifer/Beef Ym Effect, percentage points	-0.33	0.16	Standard Error	48%	Appuhamy et al., 2013
Dairy Dry Matter Intake Effect, kg/d	-0.3	-0.42, -0.18	95% Confidence Interval	40%	Duffield et al., 2008
Replacement Heifer Dry Matter Intake Effect, kg/d	-0.293	0.081	Standard Error	28%	Gadberry et al., 2022
Milk Effect, kg/d	0.7	0.49, 0.85	95% Confidence Interval	29%	Duffield et al., 2008

5.5 Deviations from Protocol Methodologies

Deviations from the methodologies in Section 5 of this protocol are not allowed.

6 Monitoring

6.1 Project Description

This project plan describes the monitoring plan to assess the GHG reductions created by the practice of feeding Rumensin to U.S. dairy cattle. The Rumensin Feed Additive Protocol was developed by Elanco to provide guidance for the creation of greenhouse gas (GHG) reductions associated with the use of Rumensin as a feed additive for U.S. dairy cattle. Rumensin improves milk production efficiency in dairy cows and reduces GHG emissions generated from enteric fermentation. It also has a secondary effect on both the GHG emissions from feed cultivation through improvements in feed efficiency and the decrease in manure production and emissions.

6.2 Project Location

Only projects located in the U.S., or on U.S. tribal lands, are eligible to generate credits under this protocol.

6.3 Project Start Date

The start date for projects is defined as the date on which practices are implemented.

6.4 Project Reporting Period

There is no minimum reporting period for projects developed under this protocol. The reporting period can be as short as desired by the project developer. The maximum reporting period is 12 months. After 12 months, a project may continue, but it must use the most recent version of this protocol. The reporting period is for the period of time during which the practices were implemented. Therefore, credits or reductions are quantified monthly on a per cow basis and summed at the herd level.

6.5 Conditions

To determine a producer’s eligibility to participate in this intervention, the verifier will determine each producer meets the following criteria:

1) The animals included in the project are animal types that are eligible to participate;
    a. Dry and lactating dairy cows
    b. Replacement heifers and non-replacement calves raised for beef purposes retained on the dairy operation
2) To qualify for this protocol, Rumensin must be fed according to label instructions at the following doses by cattle type;
    a. **Dairy cattle (dry and lactating cows):**
        i. Total Mixed Rations (“complete feed”): 11 to 22 g/ton monensin on a 100% dry matter basis.
        ii. Component Feeding Systems (including top dress):
            1. 185 to 660 mg/head/day monensin to lactating cows
            2. 115 to 410 mg/head/day monensin to dry cows

            3. This provides cows with similar amounts of monensin they would receive by consuming total mixed rations containing 11 to 22 g/ton monensin on a 100% dry matter basis.
    b. **Replacement heifers and beef animals:**
        i. 200 mg per head per day

3) The dairy farm is located in the US or US Tribal Lands
4) The start date of the project is the first day the producer demonstrates Rumensin implementation within the current calendar year
5) Signed legal attestation of voluntary compliance

6.6 Risk Mitigation

The major risk that could substantially affect the project's GHG emission reductions is in the estimation of feed intake. Traditionally a large amount of uncertainty in dairy operation greenhouse gas calculations originates from estimations of feed intake and digestibility, which vary widely between and within cattle and geographies. A significant portion of this uncertainty is mitigated in this protocol through utilizing each project's individual feed ingredient data to quantify dry matter intake and more accurately estimate gross and digestible energy. The availability of these data facilitates a precise measure of gross energy intake by cattle type from which feed cultivation, enteric, and manure emissions reductions are calculated. Because feed intake is recorded and received directly from the dairy farm, the remaining uncertainty associated with the GHG reductions quantified in this protocol arise from the adjustments made around the intervention of Rumensin implementation. These adjustments are taken directly from reputable and peer-reviewed meta-analyses. Rumensin has reliable and substantiated data regarding its mode of action and effect, and a summary of reported error associated with these effects is reported in Table 5.11. The error across the reported means that are used to calculate adjustment factors throughout this protocol averages approximately 41% of the mean.

Because uncertainty associated with feed intake, a primary driver in GHG emissions, was mitigated through incorporating project-specific feed data in a tier 2 approach to calculate GHG emissions and uncertainty associated with adjustment factors for Rumensin's effect were mitigated using meta-analyses, no deductions for uncertainty will be taken.

6.7 Roles & Responsibilities

Roles	Activities
Producer/Farm Operators	Project Proponent/Project Developers are responsible for application of feed additive and data collection
Program Administrator (Athian)	Responsible for aggregating and certifying the data from producers, verifiers and quantification tools.
GHG Emissions Quantification (Elanco/UpLook)	Collect on farm data and model the impact of on farm activities to GHG emissions
Rumensin (Elanco)	Feed Additive Producer (Elanco) and distributor
Validation & Verification	**3rd Party VVB** will validate protocol design, **3rd party VVB** will verify on farmout comes.

6.8 Monitoring Plan

A monitoring plan must be developed for all monitoring and reporting activities associated with the project. Verifiers will use the monitoring plan and report to confirm that the requirements of this protocol have been met. The monitoring plan and reports must include the following elements:

1. General description of the project, including the location of the cattle operations
2. List of the practices implemented
3. Description of the process and frequency of data collection and the archiving procedures
4. Recordkeeping plan
5. Role of any individuals performing activities related to the practices implemented
6. Quality assurance/quality control (QA/QC) procedures to ensure the accurate collection and entry of data in quantification systems
7. Monitoring reports must include the monitoring time period.
8. Monitoring reports must include the list of parameters measured and monitored.
9. Monitoring reports must include the types of data and information reported, including units of measurement.
10. Monitoring reports must include the origin of the data.
11. The monitoring report must include an attestation as to regulatory compliance.
12. The monitoring report should be submitted no less frequently than annually and no more frequently than 30 days.
13. The monitoring period can be as short as 30 days. The maximum monitoring period is 12 months.
14. The monitoring report must be submitted and shared with Athian, as the program administrator.

6.9 Managing Data Quality

UpLook

Elanco is responsible for the data quality in the UpLook tool. Athian requires Elanco (UpLook) to have the Rumensin GHG emissions quantification tool validated by an accredited 3rd party. Elanco is responsible for any changes to the monitoring data and establishing and implementing quality control procedures.

Athian

Athian directly ingests data without alteration from the UpLook API endpoint on a daily basis. This process is confirmed via Athian’s software Quality Assurance process involving both automated and manual testing to confirm expected functionality.

Additionally, data is verified via the monitoring and verification processes detailed below.

***Table 6.1** Monitoring parameters (listed in order of the equation in which they appear)*

Parameter	Description	Data Unit	Calculated (c) Measured (m) Reference (r) Operating Records (o)	Measurement Frequency	Comment
Regulations	Project developer attestation to compliance with regulatory requirements relating to the project	All applicable regulations	N/A	Every verification period	Information used to demonstrate compliance with associated regulations and rules
T	Type of cattle included in the project	Cattle type	o	Every reporting period	See Table 5.1
DMI_P^T	Average dry matter intake (DMI) of cattle type T	kg DM per head per day	o, c	Every reporting period	Originates from operating records (o), then run through an equation (c)
$EF_{feed\ i}$	Emissions factor for feed i	kg CO_2e per kg DM	r		See Tables 5.2 and 5.3 for example values
t	Number of days in the reporting period	Days	o	Every reporting period	
C^T	Number of animals fed during the feeding period for each animal type	Number of head	o	Every reporting period	
$\varphi_{feed\ i}^T$	Fractional makeup of feed i for cattle type T	Fraction	m	Every reporting period	
GWP_{CH_4}	Global warming potential of methane	tCO_2e per tCH_4	r		100-year time period from the Sixth Assessment Report from the IPCC (AR6)
$Y_{m,P}^T$	Methane Conversion Factor during the reporting period (the Methane Conversion Factor of Animals Fed Rumensin from Table 5.3)	% Gross Energy converted to methane	r		See Table 5.3 for values
GE	Gross energy concentration of diet	MJ per kg DM	o, c	Every reporting period	Originates from operating records (o), then run through an equation (c)
GWP_{N_2O}	Global warming potential of nitrous oxide	tCO_2e per tN_2O^{-1}	r		100-year time period from the Sixth Assessment Report from the IPCC (AR6)
$PS_{S,P}^T$	Percent of manure sent to (managed in) manure storage/treatment system S from cattle type T in the reporting period	%	o, c	Every reporting period	Originates from operating records (o), then run through an equation (c)
MCF_S	Methane conversion factor for storage/ treatment system S	%	r		See Table 5.9 for values
B_0^T	Maximum methane-producing capacity of manure for cattle type T	m^3 CH_4 per kg VS	r		See Table 5.4 for values

DE_P^T	Diet digestibility of cattle type T in the reporting period	% of gross energy	r		Originates from operating records (o), then run through an equation (c)
UE_P^T	Urinary energy of cattle type T in the reporting period expressed	% of gross energy	r		A default value of 4% is used for UE.
ASH_P^T	Ash content of feed for cattle type T in the reporting period	%	r		A default value of 8% is used for ash content.
$EF_{d,S}$	Emission factor for direct N_2O emissions from the manure management system S	kg N_2O-N per kg N excreted	r		See Table 5.5 for values
$N_{R\_frac}^T$	Fraction of daily N intake that is retained by the animal	kg N retained per head per day per kg N intake per head per day	r		See Table 5.6 for values
CP^T	Crude protein content in the overall diet	%	o, c	Every reporting period	Originates from operating records (o), then run through an equation (c)
M	Milk production per animal	kg per head per day	o, c	Every reporting period	Originates from operating records (o), then run through an equation (c)
M_p	Percentage of protein in the milk	%	c	Every reporting period	
$Frac_{leach\_MS_S}^T$	Fraction of managed manure nitrogen losses for livestock type T due to runoff and leaching during solid and liquid storage of manure in manure management system S	Fraction	c	Once during project	See Table 5.7 for values
EF_5	Emission factor for N2O emissions from nitrogen leaching and runoff	kg N_2O-N per kg N leached and runoff	r		See Table 5.8 for value
$Frac_{Gas\_MS_S}^T$	Fraction of managed manure nitrogen for livestock type T that volatilizes as NH_3 and NO_x in the manure management system S	Fraction	c	Once during project	See Table 5.7 for values
EF_4	Emission factor for N_2O emissions from nitrogen leaching and runoff	kg N_2O-N per kg NH_3-N + NO_x-N volatilized	r		See Table 5.8 for value
AF_{DMI}^T	DMI adjustment factor for cattle type T	Fraction	r		See Table 5.10 for values
$Y_{m,B}^T$	Methane Conversion Factor during the baseline period (the percentage of gross energy in feed converted to methane	% Gross Energy converted to methane	r		See Table 5.3 for values
AF_M^T	Milk yield adjustment factor for lactating cow type	Fraction	r		See Table 5.11 for values

7 Reporting

Project developers must provide the following documentation each reporting period to generate credits from this protocol:

1. Name and address of the project developer
2. List of all of the operations included in the project including the owner/operator contact information and address of the operation
3. Regulatory compliance documentation and attestation
4. Monitoring plan
5. Monitoring report with all the data used in the calculations for Section 5 of the protocol
6. Monitoring report must include the intended use and user of the monitoring report.

7.1 Record Keeping

For purposes of third-party verification and historical documentation, project developers must keep all information listed in this protocol for a period of 10 years after the information is generated or 7 years after the last verification. The information the project developer should retain includes:

1. All data inputs for the calculation of the project emission reductions as well as the results of emission reduction calculations
2. Copies of all permits, Notices of Violations (NOVs), and any relevant administrative or legal orders dating back at least 3 years prior to the project start date
3. All verification records and results
4. All maintenance records relevant to the monitoring equipment

7.2 Public Statements

If the project proponent makes a public statement as to conformity with ISO14064-2, the project proponent must make available to the public the following:

1. An independent third-party verification or validation statement, prepared in accordance with ISO 14064-3 OR
2. A GHG statement that includes as a minimum:
    a. The name of the project proponent
    b. a brief description of the GHG project, including size, location, duration and types of activities;
    c. a GHG statement(s), including a statement of GHG emission reductions and removal enhancements stated in units of CO_2e, e.g. tonnes of CO_2e;
    d. a statement describing whether the GHG statement has been verified and/or validated, including the type of verification or validation and level of assurance achieved;

e. a list of all relevant GHG sources and sinks controlled by the project, as well as those related to or affected by the project, including the defined criteria for their selection for inclusion in quantification;
f. a statement of the aggregate GHG emissions and/or removals by GHG SSRs for the GHG project that are controlled by the project proponent, stated in unit of CO_2e, e.g. tonnes of CO_2e, for the relevant time period (e.g. annual, cumulative to date, total);
g. a statement of the aggregate GHG emissions and/or removals by GHG SSRs for the GHG baseline, stated in units of CO_2e, e.g. tonnes of CO2e, for the relevant time period;
h. a description of the GHG baseline and demonstration that the GHG emission reductions or removal enhancements are not over-estimated;
i. a general description of the criteria, procedures or good practice guidance used as a basis for the calculation of project GHG emission reductions and removal enhancements;
j. a statement on uncertainty, how it affects the GHG statement and how it has been addressed to minimize misrepresentation;
k. the date of the report and the time period covered;
l. as applicable, an assessment of permanence;
m. an evidence of the appointment of the authorized representative on behalf of the project proponent, if different from the proponent;
n. if applicable, the GHG program(s) to which the GHG project subscribes;
o. if required by intended users, changes to the project or monitoring system from the project plan and assessment of its conformity to criteria, applicability of methodologies and any other requirements.

8 Verification

Verification bodies will contract directly with Athian for all validation and verification engagements.

Projects verified under this protocol will meet the auditing standard of reasonable assurance and adhere to 14064-3. The verification body must provide a factual statement expressing the outcome of the verification.

Issues identified during verification must be classified by verification bodies as either material (significant) or immaterial (insignificant). To be verified successfully, all reported emissions reductions must be free of material misstatements.

All projects developed under this protocol must achieve >95 percent level of accuracy. This means that the project’s calculated emission reductions must be less than 5 percent different than those calculated by the verifier.

8.1 Verification Body Requirements

To conduct verification under this protocol, all Validation and Verification Bodies (VVB) must meet the following criteria:

1. Accreditation under International Organization for Standardization (ISO) 14065: 2013 with conformance to all accreditation requirements under ISO 14065, ISO 14064-3: 2006, IAF MD 6: 2014 and all other accreditation requirements, or Acceptance in the American National Standards Institute (ANSI) accreditation program, having filed a full application for ISO 14065: 2020
2. Demonstrated/documented subject matter expertise in the on-farm operations related to an approved protocol (e.g., Dairy Operations; Feed Lot Operations)
3. Demonstrated/documented experience in a particular region or state where the verification will occur
4. Monitoring conducted in accordance with the requirements of the relevant protocol
5. Monitoring conducted in a manner that allows for a complete and transparent quantification of GHG reductions

8.2 Conflict of Interest

When conducting verification under this protocol VVBs must be seen as credible, independent, and transparent. To meet this requirement, a conflict of interest (COI) determination must be made prior to starting any verification activities. A COI occurs in any situation that compromises the VVB’s ability to perform an independent verification. Every VVB must provide information about its organizational relationships, internal structures, and management systems for identifying potential COIs. VVBs must evaluate any potential conflicting services it has provided to the project developer, including any advice or consulting provided outside of the verification process.

8.3 Verification Process

To verify the project, the VVB must develop a risk-based verification plan that takes into account the size and complexity of the project and the relevant sector, technology, and processes. The VVB must follow the following process:

1. Complete a COI evaluation. If there is a potential COI, the VVB is not allowed to conduct the verification.
2. Prepare a verification plan that includes, at a minimum:
    a. A list of people from the VVB involved in the verification,
    b. A list of the location and dates of any on-site visits that will be conducted,
    c. The types of data and documents that will be reviewed by the VVB,
    d. A list of the people who are expected to be interviewed as a part of the verification.
3. Conduct a kick-off meeting with all parties to lay out the timeline and process of the verification.
4. Undertake a desk review of the data from the project. Details for the verification items are found in Tables 8.1 and 8.2.
5. Completion of a verification report stating any issues identified during the verification and their classification as either material (significant) or immaterial (insignificant).

***Table 8.1** Eligibility verification*

Section	Eligibility Item
3	Verify that all operations are located in the United States
3	Verify the time period during which cattle are fed Rumensin is accurate
3	Verify the animals included in the project are animal types that are eligible to participate
3	Verify Rumensin was fed according to label instructions by cattle type as outlined in the eligibility requirements
3	Verify attestation of regulatory compliance

***Table 8.2** Quantification verification*

Section	Quantification Item
4	Verify that SSRs in the GHG Assessment Boundary are accounted for
5.1	Verify that DMI was calculated accurately
5.1.1	Verify that the correct emissions factors for the appropriate reasons were used
5.1.1	Verify that the feed makeup fractions were correctly determined and have supporting documentation
5.1.2	Verify that the gross energy intake for each cattle type was accurately calculated
5.1.3	Verify that the volatile solids were correctly calculated for both anaerobic and non-anaerobic storage/treatment systems
5.1.3	Verify that the correct factors were used for B_0^T, DE_B^T, UE_B^T, ASH_B^T, and MCF_{nAS}
5.2	Verify that the correct adjustment factors were used

***Table 8.3** Quantification Data Elements*

Parameter	Description	Data Unit	Data Collection & Verification Frequency	Method of Verification	QC/QA
Regulations	Project developer attestation to compliance with regulatory requirements relating to the project	All applicable regulations	Prior to the launch of an intervention and annually thereafter.	Obtain attestation from producer	Audited at verification
T	Type of cattle included in the project	Cattle type	Monthly	Data collected from UpLook as compared to on farm records	Audited at verification
DMI_P^T	Average dry matter intake (DMI) of cattle type T	kg DM per head per day	Monthly	Data collected from UpLook as compared to on farm records	Audited at verification
$EF_{feed\ i}$	Emissions factor for feed i	kg CO_2e per kg DM	Monthly	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
t	Number of days in the reporting period	Days	Monthly	Data collected from UpLook as compared to on farm records	Audited at verification

C^T	Number of animals fed during the feeding period for each animal type	Number of head	Monthly	Data collected from UpLook as compared to on farm records	Audited at verification
$\varphi^T_{feed\ i}$	Fractional makeup of feed i for cattle type T	Fraction	Monthly	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
GWP_{CH_4}	Global warming potential of methane	tCO_2e per tCH_4	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
$Y^T_{m,P}$	Methane Conversion Factor during the reporting period (the Methane Conversion Factor of Animals Fed Rumensin from Table 5.4)	% Gross Energy converted to methane	Monthly	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
GE	Gross energy concentration of diet	MJ per kg DM	Monthly	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
GWP_{N_2O}	Global warming potential of nitrous oxide	tCO_2e per tN_2O^{-1}	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
$PS^T_{S,P}$	Percent of manure sent to (managed in) manure storage/ treatment system S from cattle type T in the reporting period	%	Monthly	Data collected from UpLook as compared to on farm records	Audited at verification
MCF_S	Methane conversion factor for storage/ treatment system S	%	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
B^T_0	Maximum methane-producing capacity of manure for cattle type T	m^3 CH_4 per kg VS	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
DE^T_P	Diet digestibility of cattle type T in the reporting period	% of gross energy	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
UE^T_P	Urinary energy of cattle type T in the reporting period expressed	% of gross energy	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
ASH^T_P	Ash content of feed for cattle type T in the reporting period	%	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
$EF_{d,S}$	Emission factor for direct N_2O emissions from the manure management system S	kg N_2O-N per kg N excreted	Monthly	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification

$N_{R\_frac}^{T}$	Fraction of daily N intake that is retained by the animal	kg N retained per head per day per kg N intake per head per day	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
CP^{T}	Crude protein content in the overall diet	%	Monthly	Data collected from UpLook as compared to on farm records	Audited at verification
M	Milk production per animal	kg per head per day	Monthly	Data collected from UpLook as compared to on farm records	Audited at verification
M_p	Percentage of protein in the milk	%	Monthly	Data collected from UpLook as compared to on farm records	Audited at verification
$Frac_{leach\_MS_{S}}^{T}$	Fraction of managed manure nitrogen losses for livestock type T due to runoff and leaching during solid and liquid storage of manure in manure management system S	Fraction	At start of the verification project	Data collected from UpLook as compared to on farm records	Audited at verification
EF_5	Emission factor for N2O emissions from nitrogen leaching and runoff	kg N_2O-N per kg N leached and runoff	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
$Frac_{Gas\_MS_{S}}^{T}$	Fraction of managed manure nitrogen for livestock type T that volatilizes as NH_3 and NO_x in the manure management system S	Fraction	At start of the verification project	Data collected from UpLook as compared to on farm records	Audited at verification
EF_4	Emission factor for N_2O emissions from nitrogen leaching and runoff	kg N_2O-N per kg NH_3-N + NO_x-N volatilized	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
AF_{DMI}^{T}	DMI adjustment factor for cattle type T	Fraction	Monthly	Data collected from UpLook as compared to on farm records	Audited at verification
$Y_{m,B}^{T}$	Methane Conversion Factor during the baseline period (the percentage of gross energy in feed converted to methane	% Gross Energy converted to methane	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification
AF_{M}^{T}	Milk yield adjustment factor for lactating cow type	Fraction	Annually	Once at beginning of the verification engagement. And Annual Model Validation	Audited at verification

9 Glossary

Ash: The residue containing inorganic mineral elements of a feed sample, determined in a laboratory by burning the sample at a high temperature (removing the organic matter) and weighing the residue (i.e., ash).

Anaerobic: Conditions characterized by the absence of oxygen, which are conducive to the conversion of organic carbon into methane (CH_4) rather than carbon dioxide (CO_2).

Carbon dioxide (CO_2): The most common of the six primary GHGs, consisting of a single carbon atom and two oxygen atoms.

CO_2 equivalent (CO_2e): The quantity of a given GHG multiplied by its total global warming potential. This is the standard unit for comparing the degree of warming which can be caused by different GHGs.

Cow: Female cattle that have produced one or more calves.

Crude protein: The total nitrogen (N) in the diet, which includes true protein as well as non-protein nitrogen (e.g., urea and ammonia in a feed; nitrate is not included in non-protein nitrogen).

Digestible energy (DE): The portion of gross energy (GE) in the feed not excreted in the feces, expressed as a percentage. It is the energy from feed that is available for use by the animal.

Dry matter (DM): All the components contained in feed sample except water, including protein, fiber, fat, minerals, etc. It is the total weight of feed minus the weight of water in the feed, expressed as a percentage.

Dry matter intake (DMI): The amount of dry matter consumed by cattle.

Enteric Fermentation: The digestive process of cattle where carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream of an animal. This process releases significant amounts of methane gas.

Fat and protein corrected milk (FPCM): Milk corrected for its fat and protein content to a standard of 4.0 percent fat and 3.3 percent protein. This is a standard used for comparing milk with different fat and protein contents. It is a means of evaluating milk production of different dairy animals and breeds on a common basis.

Global warming potential: The ratio of radiative forcing (degree of warming to the atmosphere) that would result from the emission of one unit of a given GHG compared to one unit of CO_2.

Greenhouse gas (GHG): Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), or perfluorocarbons (PFCs).

Gross energy: the total energy in a feed before accounting for losses due to normal digestive, metabolic, and productive functions.

Heifer: Female cattle under 2 years of age, that have not calved.

Methane (CH_4): A GHG arising from enteric fermentation and anerobic storage of manure.

Nitrous oxide (N_2O): A GHG arising from animal wastes that occurs during both storage and treatment by the processes of nitrification and denitrification.

Solids Corrected Milk (SCM): Milk yield corrected for fat, protein, and lactose concentration according to Vasquez et al., 2021.

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