ALTERNATIVE MANURE MANAGEMENT PROTOCOL

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Athian

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1 Introduction

This protocol credits the absolute GHG reductions that result from dairy manure management practices that reduce the amount of CH_4 (and potentially N_2O, depending on the practice) emitted from manure collection, treatment, and/or storage. Four categories of project activities are eligible for crediting.

When volatile manure solids are stored in anaerobic conditions, a significant amount of methane (CH_4) and nitrous oxide (N_2O) are produced. Implementing practices that redirect the treatment of volatile manure solids from anaerobic conditions to aerobic conditions, reduces the amount of volatile manure solids managed anaerobically and results in decreases in CH_4 and N_2O emissions. Manure that is handled as a solid or is deposited on land decomposes under more aerobic conditions, causing significantly less methane production plus a small amount of nitrous oxide. Manure that is collected and/or separated can be a component of a project, but this practice must be combined with a listed treatment and/or storage practice to be eligible, since methane emissions predominantly occur during the storage and/or treatment phase.

When anaerobic storage conditions exist at a dairy facility and they implement one of the practices included in this protocol, the facility can generate impact units that can be sold to organizations looking to reduce their GHG emissions. These organizations include any offtake partners such as processors of their milk for milk products, consumer packaged goods producers (CPG's) and other retailers, all three of whom might purchase the credits and otherwise encourage the producer to implement the practices in question.

2 Project Definition

Each project must include at least one of the following eligible practices that reduce GHG emissions. Definitions of each eligible practice can be found in the glossary.

1. Pasture-based management including:
    a. conversion of a non-pasture dairy operation to pasture-based management; or
    b. at an existing pasture operation, increasing the amount of time livestock spend at pasture.

    Note: Pasture-based management projects must have previously managed or stored some manure in anaerobic conditions and introduce practices that reduce the quantity of manure managed anaerobically.
2. Alternative manure treatment and storage including:
    a. Installation of a compost bedded pack barn to compost manure on-site;
    b. Installation of slatted floor pit storage manure collection, which must be cleaned out at least monthly.

        Note: If pit storage is cleaned out less than twelve times per year, it does not qualify.
3. Conversion from a flush to scrape manure collection system in combination with one of the following practices:

a. Open solar drying of manure: manure is dried in a paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically.
b. Closed solar drying: drying of manure in an enclosed environment
c. Forced evaporation with natural gas fueled dryers
d. Daily spread: manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
e. Solid storage: manure is stored in unconfined piles or stacks
f. Composting in vessel, either:
    i. in an enclosed vessel, with forced aeration and continuous mixing; or
    ii. in an aerated static pile: composting in piles with forced aeration but no mixing.
g. Composting in windrows, either:
    i. Intensive windrows: turned at least daily for aeration;
    ii. Passive windrows: infrequent turning
h. Solid separation with an aerated vermifiltration system.

    Note: vermicomposting systems must be used in tandem with a solid separation device.

4. Solid separation of manure solids before being deposited into an anaerobic environment, paired with one of the practices (a) through (g) in the list above. Solid separation technologies include weeping walls, stationary screens, vibrating screens, screw presses, centrifuges, roller drums, belt presses/screens, advanced solid-liquid separation assisted by flocculants and/or bead filters, and vermifiltration. Additional technologies may be applicable, upon review.

    Note: Either the installation of a new solid separation system that does not currently employ solid separation, or the installation of a new solid separation system with higher separation efficiency than the existing solid separation technology may be eligible.

2.1 Impact on Yield

There is no anticipated effect on yield or productivity associated with this program. Any changes in yield will be a result of changes in dry matter intake (DMI), which are measured in both the baseline and project scenarios. Proponents are discouraged from increasing milk yield because an increase in DMI would increase the emissions in the project scenario and, therefore, decrease the GHG reductions of the project.

2.2 Causality

Causality lies in that the funding from the sale of impact units will help not only recoup the initial capital cost of implementing eligible practices, but long term to sustain the operations and maintenance and improvement of those practices. The sale of impact units on a cadence that more closely matches the flow of business and cash flow needs of the producer allows for reduced risk in the upfront capital necessary to implement new practices and to ensure their reductions to GHG outputs of the farm continue into the future.

The sale of impact units also aims to encourage the long-term maintenance of alternative manure management practices implemented under this program. This maintenance includes equipment repair and maintenance costs, energy and fuel costs, labor, and business management costs. These costs are rarely, if ever, reflected in a premium price for the product. Without continued incentives or compensation, many of these practices are not financially viable long term for farmers to implement. This results in the potential for the farmer revert to a simpler or less cost intensive practice of simply flushing the liquid manure from the dairy operations to their lagoon.

The risk of reversion or abandonment of these practices is a very real risk in the US Dairy market.

Additionally, given the highly volatile nature of farming, both due to environmental and sociopolitical pressures, any farm could potentially risk reversion or abandonment on any given day. The costs associated with the operational changes necessary to participate in this program are rarely, if ever, reflected in a premium price for the product. Without continued incentives or compensation, many of these practices pose a challenge to the farm's finances long term, threatening their continuity. This lack of compensation creates the potential for any farmer revert to simpler or less cost intensive anaerobic management practices used prior to the project.

Given both the large-scale financial risk (some of the technologies in question can cost hundreds of thousands of dollars) and the ever-changing bottom-line viability of the farm, it is incumbent on each farmer to make regular and deliberate decisions to continue with the intervention activity and actively maintain the resultant reductions in emissions. Dairy market price volatility as well as environmental threats to dairy farm profitability have been increasingly concerning. Sources such as the USDA and other leading publications note slow growth after periods of extreme volatility over the last few years. Commodity feed prices, replacement heifers, trucking, and more all also continue to increase in cost. These pressures have the potential to affect every farm on a moment's notice- a fire knocks out their feed supply (like the nearly annual major wildfires that occur in California) or a snowstorm decimates their herd (Midwest snowstorms in 2019 collapsed barns and froze large portions of herds to death), or a company the farm relied on for their operational continuity goes out of business. Since the volatility of commodity prices must be managed with the very real threats to operational continuity that these farmers deal with on a day-to-day basis, the average producer runs a great risk to the bottom-line of their farm any time they engage in a practice that does not have clear cut economic returns. Since the practices listed in Section 2 do not have these clear economic returns, every farmer who engages in the practices of this program, runs that risk of abandonment and reversion as long as they are self-funding these practices.

In providing additional funding through the sale of impact units, farmers are incentivized to not just to implement but to also maintain alternative manure management practices in the long term. This income stream allows the producer to be able to maintain their equipment and staff in such a way that reverting to anaerobic manure management is no longer the sounder business decision, thereby ensuring that the GHG reductions from the alternative manure management practices continue.

3 Eligibility

Participation in the program hinges on the implementation of improved manure management practices from predominantly anaerobic degradation to predominantly non-anaerobic degradation. For all producers participating in the program business-as-usual is defined as most of the farm's manure being managed under anaerobic conditions. On most concentrated dairy operations, this takes the form of a manure lagoon, either uncovered or covered, in which long term storage of liquid manure encourages generation of high levels of methane and nitrous oxide production. Intervention activities, conversely, create non-anaerobic environments for manure storage and breakdown either through the removal of water content prior to storage or storage in an environment that encourages drying of the manure, which leads to carbon dioxide production rather than methane and nitrous oxide.

To determine a producer's eligibility to participate in this intervention, the following data will be collected by the end of verification:

1. Animals included in the project located on a dairy operation
2. Animal types included; lactating and dry cattle and heifers
3. Evidence of the installation or implementation (in the case of non-technology based interventions) and operation of a non-digester manure management practices or technologies that avoid the anaerobic decomposition of manure volatile solids.
4. Evidence that the baseline manure management practices include the anaerobic decomposition of manure volatile solids stored in a lagoon or other predominantly liquid anaerobic environment.
5. Evidence the dairy farm is located in the US or US Tribal Lands
6. Completed legal attestation of voluntary compliance.
7. Completed legal attestation that the project activities do not cause material violations of applicable laws (e.g. water quality, safety, etc.).

To determine a producer's ongoing eligibility to participate in this intervention, the verifiers will track and monitor the following:

1. Number of cattle for each manure management system used on farm.
2. The diet of the cattle for each cattle type.
3. Frequency of cleaning of any holding areas for manure
4. Utility information pertaining to the management of manure on the farm.

3.1 Voluntary Compliance & Performance Standard

Projects must demonstrate a scenario that is "better than business-as-usual." Each producer whose dairy 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.

3.2 Project Start Date

The implementation start date for this intervention January 1, 2024 or the first active use date of the intervention activity, whichever is later. An intervention is considered in active use on the date at which the system begins to function at the intended manure intake levels upon completion of an initial start-up period. An initial start-up period must not exceed nine months. Intended manure intake levels are defined as the planned maximum manure treatment capacity of the project activity. Projects may be submitted any time after their official start date until the end of the calendar year in which they started.

3.3 Reporting Period

The preferred monitoring period is at least one calendar month and the preferred project duration is at least 12 months. Producers do have the option of choosing a quarterly monitoring period if that best fits the needs of their business, in consultation with Athian and the verifier assigned to their intervention. After 12 months using this protocol, a project may continue, but it must use the most recent version of this protocol.

3.4 Location

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

4 GHG Assessment Boundary

The sources, sinks and reservoirs (SSRs) for this protocol includes all the emissions within the farm-gate of the project. This includes all sources from waste production through disposal within the farm. **Table 4.1** provides a detailed list of the SSRs that are included, excluded, and not applicable to this protocol.

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

SSR	GHG	Included or Excluded	Justification
Feed Cultivation	CO_2, N_2O	Excluded	Emissions from the transportation, production, and harvesting of cattle feed do not change between the baseline and project scenario.
Manure Management	CH_4, N_2O	Included	Emissions from manure are reduced by the practices included in this protocol.
Fuel & Electricity Use	CO_2, CH_4, N_2O	Included	Emissions from energy use for manure management (e.g., for pumps, scrapers, vehicles, heaters, etc.) may be increased or decreased by the practices included in this protocol. Electricity emissions are CO2 only.
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.
Direct Land Use	CO_2	Excluded	Emissions from land use do not change between the baseline and project scenario.
Enteric Fermentation	CH_4	Excluded	Emissions from enteric fermentation in cattle 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 in the quantification method detailed below in Equations 5.1 through 5.39. Baseline emissions are the GHG emissions from sources within the GHG Assessment Boundary that would have occurred under the conditions of the baseline reporting period with the previous manure storage/treatment system. Project emissions are the actual GHG emissions that occur from sources within the GHG Assessment Boundary during the reporting period. Project emissions must be subtracted from baseline emissions to quantify the project's total absolute net GHG emission reductions as in Equation 5.1.

5.1 Quantification Approach

The equations and calculation methodology in this protocol are based on the Quantification Methodology of California Department of Food and Agriculture's (CDFA) Alternative Manure Management Program (AMMP). The emission factors for U.S. dairies were obtained from the USDA's Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. The equations for N_2O were taken from Volume 4, Chapter 10: Emissions from Livestock and Manure Management of the IPCC Guidelines for National Greenhouse Gas Inventories.

The CDFA methodology uses calculations to calculate GHG emission reductions achieved through the implementation of "manure management practices or technologies that avoid the anaerobic decomposition of manure volatile solids and GHG emissions associated with the implementation of AMMP projects." [1] The developers of the methodology "assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the AMMP project types." [2]

Most of the equations used in the CDFA methodology and this protocol are adapted from the California Air Resources Board's 2014 Compliance Offset Protocol for Livestock Projects. According to the CDFA methodology, "[w]hile the focus of the Livestock Protocol is the installation of a digester, the equations used to calculate current baseline scenario emissions are broadly applicable to livestock operations with anaerobic manure treatment and storage systems." [3] For both the baseline and project equations, a Tier 2 approach is used to quantify manure methane emissions.

The specific activities included in the protocol are the same as those in CDFA's AMMP. In developing the AMMP, CDFA established a Technical Advisory Committee to "obtain scientific and technical feedback on proposed programmatic components of AMMP." These individuals have "scientific and technical knowledge and expertise in manure management, methane reduction measures, [and] environmental impacts."[4] Specific variable references can be found in the table in Appendix A.

[1] California Department of Food and Agriculture (2023) Quantification Methodology. California Department of Food and Agriculture. Alternative Manure Management Program.
https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/cdfa_ammp_finalqm_6-21-23.pdf
[2] Ibid.
[3] Ibid.
[4] https://www.cdfa.ca.gov/oefi/ammp/docs/AMMP-TAC-Membership.pdf

Additional measures for conservativeness in the quantification methodology have been taken in the form of a Monte Carlo uncertainty analysis and uncertainty deduction. This uncertainty deduction aims to account for both model and parameter uncertainty. Please see Section 5.6 for additional information on the uncertainty model.

5.2 Net GHG Emission Reductions

Project emissions must be subtracted from baseline emissions to quantify the project's total absolute net GHG emission reductions as in Equation 5.1:

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

Where:

ΔGHG	=	Net GHG emissions from the project after implementation of the practices (kg CO_2e)
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_2e)
GHG_P^T	=	Total GHG emissions for cattle type T from the project scenario (kg CO_2e)

Table 5.1 *Cattle Types*

Cattle Types
Lactating Dairy Cows (Freestall)
Lactating Dairy Cows (Open Lot)
Dry Dairy Cows
All Other Types (including replacement heifers and dairy beef steers)

5.3 Baseline GHG Emissions

The baseline scenario is the situation where, in the absence of the intervention activity, any animal manure produced during the monitoring period is left to degrade in a predominantly anaerobic environment and the resultant CH_4 and N_2O is emitted to the atmosphere. More simply, the baseline scenario is the manure management system used on the farm in the absence of alternative manure management practices, in the average environmental conditions of the current monitoring period. In the baseline scenario, the retention time of manure waste in the anaerobic treatment system is greater than one month, and if anaerobic lagoons are used in the baseline, their depths are at least 1m (CDM AMS-III.d).

Baseline electricity and fuel emissions are averages based on sources within the GHG assessment boundary on data from the 2 years prior to the installation or implementation of the project. This baseline is based on methodologies from the U.S. Livestock Project Protocol and the CDM AMS-III.d Small-Scale Methodology: Methane recovery in animal manure systems program.

Baseline manure emissions represent the emissions that would have occurred with the previous manure management system (i.e. business-as-usual, the manure management that would have occurred in the absence of the project) under the conditions of the baseline period. This baseline is established on averages of data from the 2 years prior to the implementation start date of the intervention.

$$GHG^{T}_{B} = GHG^{T}_{man,\,B} + GHG^{T}_{elec,B} + GHG^{T}_{fuel,B} \quad \text{(Equation 5.2)}$$

Where:

$GHG^{T}_{man,B}$	=	Baseline GHG emissions from manure for cattle type T during the reporting period (kg CO_2e) that would have occurred in the absence of the project
$GHG^{T}_{elec,B}$	=	Baseline GHG emissions from electricity use for manure management activities for cattle type T during the reporting period (kg CO_2e) that would have occurred in the absence of the project
$GHG^{T}_{fuel,B}$	=	Baseline GHG emissions from fuel use for manure management for cattle type T during the reporting period (kg CO_2e) that would have occurred in the absence of the project

5.3.1 Baseline GHG Emissions from Manure Management

Baseline GHG emissions from manure production and management are calculated according to Equations 5.3 to 5.20:

$$GHG^{T}_{man,B} = \sum_{T} ((CH^{T}_{4\,man,\,B} \times GWP_{CH_4}) + (N_2O^{T}_{man,\,B} \times GWP_{N_2O})) \quad \text{(Equation 5.3)}$$

Where:

$CH^{T}_{4\,man,\,B}$	=	Baseline methane emissions from manure for cattle type T during the reporting period that would have occurred in the absence of the project (kg CH_4)
GWP_{CH4}	=	Global warming potential of methane (kgCO_2e kgCH_4^{-1})
$N_2O^{T}_{man,\,B}$	=	Baseline nitrous oxide emissions from manure production for cattle type T during the reporting period that would have occurred in the absence of the project (kg N_2O)
GWP_{N_2O}	=	Global warming potential of nitrous oxide (kg CO_2e kg N_2O^{-1})

5.3.1.1 Baseline Manure Methane Emissions

Baseline methane emissions from manure management are the sum of methane emissions from the predominantly anaerobic (liquid) storage/treatment systems and predominantly non-anaerobic (dry/solid) storage/treatment systems that would have occurred in the absence of the project. Manure methane emissions are calculated using a Tier 2 approach consistent with both IPCC and Environmental Protection Agency (EPA) quantification methodologies. This protocol also leverages the approaches used by the Climate Action Reserve's U.S. Livestock Project Protocol, the California Air Resources Board's Compliance Offset Protocol for capturing and destroying methane from manure management systems, and the quantification methodology for California Department of Food and Agriculture's Alternative Manure Management Program (Climate Action Reserve, 2013; California Air Resources Board, 2014, 2023).

$$CH^{T}_{4\,man,\,B} = CH^{T}_{4\,liq,\,B} + CH^{T}_{4\,dry,\,B} \qquad \text{(Equation 5.4)}$$

Where:

$CH^{T}_{4\,liq,\,B}$	=	Baseline methane emissions from manure for cattle type T in predominantly anaerobic (liquid) manure storage/treatment that would have occurred during the reporting period in the absence of the project (kg CH_4)
$CH^{T}_{4\,dry,\,B}$	=	Baseline methane emissions from manure for cattle type T in predominantly non-anaerobic (dry/solid) manure storage/treatment that would have occurred during the reporting period in the absence of the project (kg CH_4)

5.3.1.1.1 Baseline Manure Methane Emissions from Anaerobic Storage/Treatment

$$CH^{T}_{4\,liq,\,B} = \sum_{AS,T} (VS^{T}_{deg,AS,B} \times B^{T}_{0}) \times \rho_{CH_4} \qquad \text{(Equation 5.5)}$$

Where:

$VS^{T}_{deg,AS,B}$	=	Volatile solids from cattle type T that would have degraded during the reporting period in anaerobic storage/treatment system AS in the absence of the project (kg dry matter)
B^{T}_{0}	=	Maximum methane-producing capacity of manure for cattle type T (see **Table 5.2**, m^3 CH_4 kg VS^{-1})
ρ_{CH_4}	=	Density of methane = 0.67 (1 atm, 60°F) (kg m^{-3})[5]

With:

$$VS^{T}_{deg,AS,B} = f_{i} \times VS^{T}_{avail,AS,B,i} \qquad \text{(Equation 5.6)}$$

Where:

f_i	=	The van't Hoff-Arrhenius factor for the current reporting period i
$VS^{T}_{avail,AS,B,i}$	=	Volatile solids from cattle type T that would have been available for degradation during the current reporting period i in anaerobic storage/treatment system AS in the absence of the project (kg dry matter)

With:

[5] Taken from Equation 5-26 of Powers et al. 2014

$$f_i = MIN(exp\left[\frac{E(T_2 - T_1)}{R T_1 T_2}\right], 0.95)$$ (Equation 5.7)

Where:

E	=	Activation energy constant (15,175 cal/mol)
T_1	=	303.16 Kelvin
T_2	=	Average ambient temperature (K) in the reporting period (K = ˚C + 273). If T_2 < 5˚C, then f = 0.104.
R	=	Ideal gas constant (1.987 cal/K-mol)

And:

$$VS^T_{avail,AS,B,i} = \left(VS^T_i \times C^T_i \times PS^T_{AS,B,i} \times t_i \times 0.8\right) + (VS^T_{avail,AS,B,i-1} - VS^T_{deg,AS,B,i-1})$$ (Equation 5.8)[6]

Where:

VS^T_i	=	Volatile solids produced by cattle type T on a dry matter basis during the reporting period i (kg cattle^{-1} day^{-1})
C^T_i	=	Average number of animals for each cattle type T during the reporting period i
$PS^T_{AS,B,i}$	=	Percent of manure solids that would have been sent to (managed in) anaerobic manure storage/treatment system AS from cattle type T during the reporting period i in the absence of the project. Dairy-specific data must be used.[7]
t_i	=	Number of days in the reporting period i
0.8	=	System calibration factor[8]
$VS^T_{avail,AS,B,i-1}$	=	Volatile solids from cattle type T from the previous reporting period $i-1$ that would have been available for degradation in anaerobic storage/treatment system AS (kg dry matter) in the absence of the project.[9]
$VS^T_{deg,AS,B,i-1}$	=	Volatile solids from cattle type T that would have degraded during the previous reporting period $i-1$ in anaerobic storage/treatment system AS in the absence of the project (kg dry matter)

[6] Equation from CDFA AMMP, page 13
[7] The value of PSAS,B,iT must take into account: the fraction of volatile solids that would have been recoverable (i.e., able to be collected for transfer into the baseline anaerobic storage/treatment system) in the absence of the project, which is a function of the amount of time animals would have spent in different enclosure types; the type and efficiency the baseline manure collection system; and the efficiency of the baseline solid separation technology, if any.
[8] From California Air Resources Board (2023) and US EPA (2016).
[9] For the first reporting period of the project, if there are no site-specific data on the mass of volatile solids in the anaerobic storage/treatment system at the beginning of the project, the value may be calculated in one of two ways. If there are monthly data on herd characteristics, animal diet, and average site temperature since the last cleanout of the anaerobic storage/treatment system, the amount of volatile solids at the beginning of the project shall be calculated by setting (VSavail,AS,B,i-1T- VSdeg,AS,B,i-1T) to zero in the month following the cleanout and using the equations in this protocol to calculate the buildup of volatile solids in the months since the cleanout. Otherwise, (VSavail,AS,B,i-1T- VSdeg,AS,B,i-1T) will be set to zero in the first reporting period. If the retention time for volatile solids in the anaerobic storage/treatment system is less than or equal to 30 days, set (VSavail,AS,B,i-1T- VSdeg,AS,B,i-1T) to zero. Similarly, for any reporting period following the complete drainage and cleaning of solid buildup from the anaerobic storage/treatment system, (VSavail,AS,B,i-1T- VSdeg,AS,B,i-1T) must be set to zero.

$$VS_i^T = \left[DMI^T \times \left(1 - DE^T\right) + \left(UE^T \times DMI^T\right)\right] \times \left(1 - ASH^T\right) \quad \text{(Equation 5.9)}$$

Where:

DMI^T	=	Average dry matter intake per animal of cattle type T (kg head^{-1} day^{-1}) during the reporting period. Calculated based on known intake (feedyard) or estimated intake equations (other cattle categories)
DE^T	=	Diet digestibility of the feed for cattle type T in the reporting period as a fraction of gross energy (see **Table 5.3**) (dimensionless) Where DE is not available from primary data sources, projects may choose to use the Athian Dairy Total Digestible Nutrients Tool instead. Methodology for this tool is available as **Appendix C. Athian Dairy Total Digestible Nutrients Tool Methodology.**
UE^T	=	Urinary energy of cattle type T in the reporting period expressed as a fraction of gross energy (dimensionless). A default value of 4% is used for UE. This value can be reduced to 2% for cattle fed with 85 percent or more grain in their diet.
ASH^T	=	Ash content of feed for cattle type T in the reporting period (see **Table 5.3**) (%)

DE and Ash are calculated as a weighted average using the data from **Table 5.3**. Producers may provide alternative approaches to determine DE and Ash content of feed.

Table 5.2 *Maximum Methane-producing Capacity of Manure for Cattle*[10]

Cattle Types (T)	B_0^T (m^3 CH_4 kg^{-1} VS added)
Dairy Cattle (both dry and lactating)	0.24
Replacement Heifers	0.17
Dairy Beef Steers	0.33

Table 5.3 *Examples of DE and Ash Content by Feed Type*[11]

Feed	DE (% of GE)	Ash %
Alfalfa hay early bloom	63.72	8
Alfalfa silage	60.71	9
Corn grain, whole	88.85	2
Corn silage, mature well eared	72.88	5
DDGS, dry mill	76.88	4
Distillers grain, corn with solubles	81.50	5
Grass hay	N/A	6
Grass silage	N/A	8
Oat grain	75.63	4
Soybean hulls	66.86	5
Soybean meal, solv. ext. 44% CP	79.50	7

[10] Table from Table 5-19 of Powers et al. 2014.
[11] Taken from Appendix 5-B of Powers et al. 2014. Additional feed values are available in the Powers Appendix.

Winter wheat grain	86.45	2
Canola meal, solv. ext	N/A	8
Cottonseed, whole	N/A	5
Citrus pulp dried	N/A	7
Wheat midds	N/A	5

5.3.1.1.2 Baseline Manure Methane Emissions from Non-Anaerobic Storage/Treatment

$$CH^{T}_{4\,dry,B} = \sum_{S,T} (C^{T}_{i} \times VS^{T}_{i} \times PS^{T}_{S,B,i} \times MCF_{S} \times B^{T}_{0} \times \rho_{CH_4} \times t) \quad \text{(Equation 5.10)}$$

Where:

C^{T}	=	Average number of animals for each cattle type T during the reporting period
VS^{T}	=	Volatile solids produced by cattle type T on a dry matter basis during the reporting period (kg cattle^{-1} day^{-1})
$PS^{T}_{S,B,i}$	=	Percent of manure solids that would have been sent to (managed in) non-anaerobic manure storage/treatment system S from cattle type T during the reporting period in the absence of the project. Dairy-specific data must be used.[12]
MCF_{S}	=	Methane conversion factor for non-anaerobic manure storage/treatment system S during the reporting period, based on T_2, in **Table 5.4** (%)
B^{T}_{0}	=	Maximum methane-producing capacity of manure for cattle type T in **Table 5.2** (m^3 CH_4 kg VS^{-1})
ρ_{CH_4}	=	Density of methane = 0.67 (1 atm, 60°F) (kg m^{-3})
t	=	Number of days in the reporting period

$$VS^{T}_{i} = \left[DMI^{T} \times \left(1 - DE^{T}\right) + \left(UE^{T} \times DMI^{T}\right)\right] \times (1 - ASH^{T}) \quad \text{(Equation 5.11)}$$

Where:

DMI^{T}	=	Dry matter intake of cattle type T in the reporting period (kg)
DE^{T}	=	Diet digestibility of the feed for cattle type T in the reporting period as a fraction of gross energy (see **Table 5.3**) (%) Where DE is not available from primary data sources, projects may choose to use the Athian Dairy Total Digestible Nutrients Tool instead. Methodology for this tool is available as **Appendix C. Athian Dairy Total Digestible Nutrients Tool Methodology.**
UE^{T}	=	Urinary energy of cattle type T in the reporting period expressed as a fraction of gross energy (dimensionless). A default value of 4% is used for UE. This value can be reduced to 2% for cattle fed with 85 percent or more grain in their diet.

[12] The value of PSS,BT must take into account the fraction of volatile solids that would have been deposited on land (e.g., pasture, open lot) and the fraction that would have been recoverable (i.e., able to be collected for transfer into a non-anaerobic storage/treatment system, if any) in the absence of the project. These fractions are functions of the amount of time animals would have spent on pasture vs. different enclosure types in the absence of the project. PSS,BT also depends on the type and efficiency of the baseline manure collection system in collecting recoverable manure and the efficiency of the baseline solid separation technology, if any.

ASH^T	=	Ash content of feed for cattle type T in the reporting period (see **Table 5.3**) (dimensionless)

Table 5.4 *Methane Conversion Factor (MCF) for Non-Anaerobic Storage / Treatment Systems.*[13] *System definitions are in Table 5.5.*

System	Average Temperature in Reporting Period, T2 (˚C)									
	<10	≤11	≤12	≤13	≤14	≤15	≤16	≤17	≤18	≤19
Pasture/Range/ Paddock	1%	1%	1%	1%	1%	1.5%	1.5%	1.5%	1.5%	1.5%
Daily Spread	0.1%	0.1%	0.1%	0.1%	0.1%	0.5%	0.5%	0.5%	0.5%	0.5%
Solid Storage	2%	2%	2%	2%	2%	4%	4%	4%	4%	4%
Dry Lot	1%	1%	1%	1%	1%	1.5%	1.5%	1.5%	1.5%	1.5%
Liquid/Slurry (With Natural Crust Cover)	10%	11%	13%	14%	15%	17%	18%	20%	22%	24%
Liquid/Slurry (Without Natural Crust Cover)	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%
Pit Storage (<1 Month)	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Pit Storage (>1 Month)	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%
Deep Bedding (<1 Month)	3%	3%	3%	3%	3%	3%	3%	3%	3%	3%
Deep Bedding (>1 Month)	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%
Composting -- In-Vessel Or Aerated Static Pile	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Composting -- Windrows	0.5%	0.5%	0.5%	0.5%	0.5%	1%	1%	1%	1%	1%
Weeping Wall	22%	22%	22%	22%	22%	22%	22%	22%	22%	22%

Table 5.4 *Methane Conversion Factor (MCF) for Non-Anaerobic Storage / Treatment Systems, Continued. Note: Any monthly average greater than 28˚C should utilize the MCF listed for 28˚C*

System	Monthly Average Temperature Range (˚C)								
	<20	≤21	≤22	≤23	≤24	≤25	≤26	≤27	≤28
Pasture/Range/ Paddock	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	2%	2%	2%
Daily Spread	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	1%	1%	1%
Solid Storage	4%	4%	4%	4%	4%	4%	5%	5%	5%

[13] Values from CDFA (2023) AMMP Draft Benefits Calculator Tool. The monthly average ambient temperature for the reporting period must be obtained from the closest weather station with available data; if applicable, the weather station should be located in the same air basin.

Dry Lot	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	2%	2%	2%
Liquid/Slurry (With Natural Crust Cover)	26%	29%	31%	34%	37%	41%	44%	48%	50%
Liquid/Slurry (Without Natural Crust Cover)	42%	46%	50%	55%	60%	65%	71%	78%	80%
Pit Storage (<1 Month)	3%	3%	3%	3%	3%	3%	3%	3%	3%
Pit Storage (>1 Month)	42%	46%	50%	55%	60%	65%	71%	78%	80%
Deep Bedding (<1 Month)	3%	3%	3%	3%	3%	3%	3%	3%	3%
Deep Bedding (>1 Month)	42%	46%	50%	55%	60%	65%	71%	78%	90%
Composting -- In-Vessel Or Aerated Static Pile	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Composting -- Windrows	1%	1%	1%	1%	1%	1%	1.5%	1.5%	1.5%
Weeping Wall	22%	22%	22%	22%	22%	22%	22%	22%	22%

5.3.1.2 Baseline Manure Nitrous Oxide Emissions

Baseline emissions of N_2O are calculated as follows:

$$N_2O^T_{man,B} = \sum_T (N_2O^T_{dir,B} + N_2O^T_{ind,l,B} + N_2O^T_{ind,v,B}) \qquad \textit{(Equation 5.12)}$$

Where:

$N_2O^T_{dir,B}$	=	Direct N_2O emissions from management of manure from cattle type T that would have occurred in the absence of the project (kg N_2O)
$N_2O^T_{ind,l,B}$	=	Indirect N_2O emissions from leaching of manure from cattle type T that would have occurred in the absence of the project (kg N_2O)
$N_2O^T_{ind,v,B}$	=	Indirect N_2O emissions from cattle type T from the volatilization of NH_3 and NO_x that would have occurred in the absence of the project (kg N_2O)

5.3.1.2.1 Baseline Direct N_2O 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 shall then be calculated using Equation 5.13:

$$N_2O^T_{dir,B} = (\sum_S(\sum_T(C^T \times N^T_{ex} \times AWMS_{S,TB}))) \times EF_{dir,S} \times \frac{44}{28} \qquad \textit{(Equation 5.13)}$$

Where:

C^T	=	Average number of animals for each cattle type T during the reporting period
$EF_{dir,S}$	=	Emission factor for direct N_2O emissions from non-anaerobic manure management system S (dimensionless) in **Table 5.5**.
$\frac{44}{28}$	=	Conversion factor between $N_2O{-}N$ emissions and N_2O emissions
N^T_{ex}	=	Average N excretion per animal of cattle type T (kg head^{-1})
$AWMS_{S,TB}$	=	Baseline fraction of total annual volatile solids for each livestock category T that is managed in manure management system S.

Table 5.5 *Default Emission Factors for Direct N_2O Emissions from Manure Management*[14]

System	Definition	$EF_{dir,S}$
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.	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

[14] Adapted from Table 10.21 in Chapter 10 of IPCC (2019).

System	Definition		$EF_{dir,S}$
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
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

System	Definition		$EF_{dir,S}$
		Forced aeration systems	0.005

Rates of N excretion are calculated using Equations 5.14 and 5.15:

$$N^T_{ex} = N^T_{in} \times \left(1 - N^T_{ret}\right) \times t \qquad \text{(Equation 5.14)}$$

$$N^T_{in} = DMI^T_{per} \times \frac{\frac{CP^T}{100}}{6.25} \qquad \text{(Equation 5.15)}$$

Where:

N^T_{in}	=	Average daily nitrogen intake per animal of cattle type T in the reporting period (kg head^{-1} day^{-1})
N^T_{ret}	=	Fraction of daily N intake that is retained by cattle type T (dimensionless). Calculated according to **(Equation 5.16)**.
DMI^T_{per}	=	Average dry matter intake per animal of cattle type T (MJ head^{-1} day^{-1}) during the reporting period. Calculated based on known intake (feedyard) or estimated intake equations (other cattle categories)
CP^T	=	Crude protein content in the overall diet for cattle type T in the reporting period (%)
t	=	Number of days in the reporting period

The fraction of nitrogen retained by the animal is calculated according to Equation 5.16:

$$N^T_{ret} = \frac{M \times \left(\frac{M_p}{100}\right)}{6.38} + \frac{WG^T \times \frac{268 - \frac{7.03 \times NE_g}{WG}}{1000}}{6.25} \qquad \text{(Equation 5.16)}$$

$$NE_g = 22.02 \times \left(\frac{BW^T}{\gamma \times MW^T}\right)^{0.75} \times \left(WG^T\right)^{1.097} \qquad \text{(Equation 5.17)}$$

Where:

M	=	Average milk production per cow during the reporting period (kg head^{-1} day^{-1}); this is 0 for other cattle types
M_p	=	Percentage of protein in the milk during the reporting period (%)

6.38	=	Conversion factor from milk protein to milk nitrogen (dimensionless)
WG^T	=	Average weight gain of the animals in the population of cattle type T (kg day^{-1}). Note: because lactating and dry cattle are assumed to have no weight gain or loss per **Table 5.6-C** and setting WG(T) to 0 would cause an error in the calculation, the second half of **Equation 5.17** is set to 0 for lactating and dry cattle.
1,000	=	Conversion from g to kg
NE_G	=	Net energy for growth (MJ day^{-1})
268	=	Constant derived from Equation 3-8 in NRC (1996), g protein kg^{-1} animal^{-1}
7.03	=	Constant derived from Equation 3-8 in NRC (1996), g protein MJ^{-1} animal^{-1}
6.25	=	Conversion factor from kg of dietary crude protein to kg of dietary N (dimensionless)
BW^T	=	Average live body weight (BW) of the animals in the population of cattle type T in kg, Table 5.6-B
γ	=	Coefficient (dimensionless) with a value of 0.8 for females (heifers & cows), 1.0 for castrates (steers, mixed & holsteins), and 1.2 for bulls (NRC, 1996)
MW^T	=	Mature live body weight of an adult animal of cattle type T in moderate body condition in kg, either from producer records or using defaults in **Table 5.6**

***Table 5.6-A** Mature Weights by Cattle Type*

Cattle Type	MW	Note
Dairy cows	650 kg	Derived from IPCC guidance from 2019. This value applies for lactating dairy cattle, dry dairy cattle, and dairy heifers.
Dairy beef steers	820 kg	Derived from IPCC guidance from 2019.

***Table 5.6-B** Average Live Body Weight by Cattle Type. Mature weights listed in Table 5.6-A.*

Cattle Type	BW^T	Note
Lactating Cows	650 kg	Derived from IPCC guidance from 2019
Dry Cows	650 kg	Derived from IPCC guidance from 2019
Replacement Heifers	400 kg	Derived from IPCC guidance from 2019
Dairy Beef Steers	300kg	Derived from IPCC guidance from 2019

***Table 5.6-C** Weight Gain Per Day by Cattle Type*

Cattle Type	WG^T	Note
Lactating Cows	0 kg/day	Derived from IPCC guidance from 2019
Dry Cows	0 kg/day	Derived from IPCC guidance from 2019
Replacement Heifers	0.5 kg/day	Derived from IPCC guidance from 2019

Dairy Beef Steers	0.5 kg/day	Derived from IPCC guidance from 2019

5.3.1.2.2 Baseline Indirect N_2O Emissions from Leaching of Manure

Nitrogen is lost through runoff and leaching into soils from the solid storage of manure in outdoor areas and feedlots. The baseline amount of nitrous oxide that would have been emitted through leaching in the absence of the project shall be calculated using Equation 5.18:

$$N_2O^T_{ind,l,B} = \sum_S(\sum_T(C^T \times N^T_{ex} \times AWMS_{S,TB} \times PL^T_S)) \times EF_l \times \frac{44}{28} \quad \text{(Equation 5.18)}$$

Where:

C^T	=	Average number of animals for each cattle type T during the reporting period
N^T_{ex}	=	Average N excretion per animal of cattle type T (kg head^{-1})
PL^T_S	=	Percent of managed manure nitrogen losses for cattle type T due to runoff and leaching during solid and liquid storage of manure in non-anaerobic manure management system S (Table 5.7) (%)
EF_l	=	Emission factor for N_2O emissions from nitrogen leaching and runoff. The default value is 0.011 kg N_2O-N (kg N leaching/runoff)[15]
$\frac{44}{28}$	=	Conversion factor between $N_2O{-}N$ emissions and N_2O emissions
$AWMS_{S,TB}$	=	Baseline fraction of total annual volatile solids for each livestock category T that is managed in manure management system S

Table 5.7 *Percent of managed manure nitrogen losses due to leaching and volatilization in manure management systems.* [16] *System definitions are in **Table 5.5**.*

System	PL^T_S (%)	PV^T_S (%)
Pasture/Range/Paddock	Indirect N_2O emissions associated with the manure deposited on agricultural soils and pasture, range, and paddock systems are not included in this protocol.	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	0	7
Solid Storage	2	30
Solid Storage – Covered/Compacted	0	14
Solid Storage – Bulking Agent Addition	2	38

[15] Additional emission factors may be used from Table 11.3 in Chapter 11 of IPCC (2019).
[16] From Table 10.22 in Chapter 10 of IPCC (2019).

Solid Storage – Additives		2	11
Dry Lot		3.5	30
Liquid/Slurry	With natural crust cover	0	30
	Without natural crust cover	0	48
	Cover	0	10
Uncovered Anaerobic Lagoon		0	35
Pit Storage Below Animal Confinements		0	28
Deep Bedding	No mixing	3.5	25
	Active mixing	3.5	25
Composting – In-Vessel		0	45
Composting – Static Pile (Forced Aeration)		6	50
Composting – Intensive Windrow (Frequent Turning)		6	50
Composting – Passive Windrow (Infrequent Turning)		4	45

5.3.1.2.3 Baseline Indirect N_2O 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 baseline amount of nitrous oxide emitted through volatilization in the forms of NH_3 and NO_x shall be calculated using Equation 5.19:

$$N_2O^T_{ind,v,B} = \sum_S(\sum_T(C^T \times N^T_{ex} \times AWMS_{S,TB} \times PV^T_S) \times EF_v \times \frac{44}{28} \quad \text{(Equation 5.19)}$$

Where:

C^T	=	Average number of animals for each cattle type T during the reporting period
N^T_{ex}	=	Average N excretion per animal of cattle type T (kg head^{-1})
PV^T_S	=	Percent of managed manure nitrogen for livestock type T that volatilizes as NH_3 and NO_x from non-anaerobic manure management system S (**Table 5.7**) (%)
EF_v	=	Emission factor for N_2O emissions from nitrogen volatilization. The default value is 0.010 kg N_2O-N (kg N leaching/runoff)[17]
$\frac{44}{28}$	=	Conversion factor between $N_2O{-}N$ emissions and N_2O emissions

[17] Additional emission factors may be used from Table 11.3 in Chapter 11 of IPCC (2019).

$AWMS_{S,TB}$	=	Baseline fraction of total annual volatile solids for each livestock category T that is managed in manure management system S

5.3.2 Baseline CO_2 Emissions from Electricity Use

Baseline CO_2 emissions from electricity consumption are determined using averages from the 24 months prior to the adoption of alternative manure management practices. In the absence of manure management-specific data (i.e., electricity consumed by equipment for activities including but not limited to moving, treating, drying, storing, and spreading manure) for each cattle type, total electricity consumption by the dairy may be used. CO_2 emissions from electricity use are calculated by multiplying the total quantity of electricity consumed and the emissions factor for electricity for the state in which the dairy is located.

$$GHG^{T}_{elec,B} = Elec^{T}_{B} \times EF_{elec} \times \frac{1}{2.2046} \quad \text{(Equation 5.20)}$$

Where:

$GHG^{T}_{elec,B}$	=	Baseline CO_2 emissions from electricity use for manure management activities for cattle type T that would have occurred during the reporting period in the absence of the project (kg CO_2)
$Elec^{T}_{B}$	=	The average amount of electricity that would have been used for manure management activities for cattle type T in the absence of the project, based on average electricity consumption for the same time as the reporting period from the 2 years prior to the project start date[18] (MWh)
EF_{elec}	=	Emissions factor for electricity in the state in which the dairy is located (lbs CO_2/MWh)[19]
2.2046	=	Conversion factor from lbs to kg

5.3.3 Baseline GHG Emissions from Fuel Use

Baseline GHG emissions from fossil fuel use are determined using averages from the 24 months prior to the adoption of alternative manure management practices. In the absence of manure management-specific data (e.g., fuel consumed by equipment for manure management, including but not limited to generators for pumps, manure drying equipment, vehicles, etc.), total fuel consumption by the dairy may be used. GHG emissions from fuel use are calculated by multiplying the total quantity of each type of fuel used and the emissions factor for that type of fuel and then summing the terms.

$$GHG^{T}_{fuel,B} = \sum_{f}\left(Fuel^{T}_{f,B} \times EF_{fuel,f}\right) \quad \text{(Equation 5.21)}$$

Where:

[18] For instance, if the current reporting period is January, the baseline will be the average electricity use of the two Januarys prior to the start of the project.
[19] State-specific emissions factors are available via U.S. Energy Information Administration (2023). US Electricity Profile 2022. https://www.eia.gov/electricity/state/

$GHG^{T}_{fuel\,B}$	=	Baseline GHG emissions from fuel use for manure management activities for cattle type T that would have occurred during the reporting period in the absence of the project (kg CO_2eq)
$Fuel^{T}_{f,B}$	=	The average amount of fuel that would have been used for manure management activities for cattle type T in the absence of the project, based on average fuel consumption for the same time as the reporting period from the 2 years prior to the project start date[20] (mmBtu or gallon)
$EF_{fuel,\,f}$	=	Fuel-specific emission factor (Table 5.8, kg/mmBtu or kg/gal)

Table 5.8 *Fuel-specific emissions factors*[21]

Fuel Type	EF_{f}	Unit
Diesel	10.229	kg CO_2e / gallon
Fuel Oil	10.998	kg CO_2e / gallon
Kerosene	10.184	kg CO_2e / gallon
Propane	5.742	kg CO_2e / gallon
Gasoline	8.813	kg CO_2e / gallon
Natural Gas	53.117	kg CO_2e / mmBtu

5.4 Project GHG Emissions

Project GHG emissions for each reporting period are the sum of emissions from manure, electricity use, and fuel consumption in that reporting period, as calculated in Equation 5.22:

$$GHG^{T}_{P} = GHG^{T}_{man,\,P} + GHG^{T}_{elec,P} + GHG^{T}_{fuel,P} \quad \text{(Equation 5.22)}$$

Where:

$GHG^{T}_{man,P}$	=	Project GHG emissions from manure for cattle type T during the reporting period (kg CO_2e)
$GHG^{T}_{elec,P}$	=	Project GHG emissions from electricity use for manure management activities for cattle type T during the reporting period (kg CO_2e)
$GHG^{T}_{fuel,P}$	=	Project GHG emissions from fossil fuel use for manure management for cattle type T during the reporting period (kg CO_2e)

[20] For instance, if the current reporting period is January, the baseline will be the average fuel consumption of the two Januarys prior to the start of the project.
[21] Values calculated from data in U.S. Environmental Protection Agency. (2023). Emissions Factors for Greenhouse Gas Inventories. https://www.epa.gov/system/files/documents/2023-03/ghg_emission_factors_hub.pdf using GWP_{CH4} = 29.8 and GWP_{N2O} = 273 (Forster et al. 2021).

5.4.1 Project GHG Emissions from Manure Management

Project GHG emissions from manure production and management are calculated according to Equations 5.23 to 5.34:

$$GHG^{T}_{man,P} = \sum_{T}((CH^{T}_{4\,man,\,P} \times GWP_{CH_4}) + (N_2O^{T}_{man,\,P} \times GWP_{N_2O})) \qquad \text{(Equation 5.23)}$$

Where:

$CH^{T}_{4\,man,\,P}$	=	Project methane emissions from manure for cattle type T during the reporting period (kg CH_4)
GWP_{CH4}	=	Global warming potential of methane ($tCO_2e\ tCH_4^{-1}$)
$N_2O^{T}_{man,\,P}$	=	Project nitrous oxide emissions from manure production for cattle type T during the reporting period (kg N_2O)
GWP_{N_2O}	=	Global warming potential of nitrous oxide (kg CO2e kg N_2O^{-1})

5.4.1.1 Project Manure Methane Emissions

Project methane emissions from manure management are the sum of methane emissions from the predominantly anaerobic (liquid) storage/treatment systems and predominantly non-anaerobic (dry/solid) storage/treatment systems of the project.

$$CH^{T}_{4\,man,\,P} = CH^{T}_{4\,liq,\,P} + CH^{T}_{4\,dry,\,P} \qquad \text{(Equation 5.24)}$$

Where:

$CH^{T}_{4\,liq,\,P}$	=	Project methane emissions from manure for cattle type T in predominantly anaerobic (liquid) manure storage/treatment during the reporting period (kg CH_4)
$CH^{T}_{4\,dry,\,P}$	=	Project methane emissions from manure for cattle type T in predominantly non-anaerobic (dry/solid) manure storage/treatment during the reporting period (kg CH_4)

5.4.1.1.1 Project Manure Methane Emissions from Anaerobic Storage/Treatment

$$CH^{T}_{4\,liq,\,P} = \sum_{S,T}(VS^{T}_{deg,AS,P} \times B^{T}_{0}) \times \rho_{CH_4} \qquad \text{(Equation 5.25)}$$

Where:

$VS^{T}_{deg,AS,P}$	=	Volatile solids from cattle type T degraded during the reporting period in anaerobic project storage/treatment system AS (kg dry matter)
B^{T}_{0}	=	Maximum methane-producing capacity of manure for cattle type T (Table 5.2 Maximum Methane-producing Capacity of Manure for Cattle, $m^3\ CH_4$ kg VS^{-1})
ρ_{CH_4}	=	Density of methane = 0.67 (1 atm, 60°F) (kg m^{-3})

With:

$$VS^T_{deg,AS,P} = f_i \times VS^T_{avail,AS,P,i} \quad \text{(Equation 5.26)}$$

Where:

f_i	=	The van't Hoff-Arrhenius factor for the current reporting period i
$VS^T_{avail,AS,P,i}$	=	Volatile solids from cattle type T available for degradation during the current reporting period i in anaerobic project storage/treatment system AS (kg dry matter)

With:

$$f_i = MIN(exp\left[\frac{E(T_2 - T_1)}{R\,T_1 T_2}\right], 0.95) \quad \text{(Equation 5.27)}$$

Where:

E	=	Activation energy constant (15,175 cal/mol)
T_1	=	303.16 Kelvin
T_2	=	Average ambient temperature (K) in the reporting period (K = ˚C + 273). If T_2 < 5˚C, then f = 0.104.
R	=	Ideal gas constant (1.987 cal/K-mol)

And:

$$VS^T_{avail,AS,P,i} = \left(VS^T_i \times C^T_i \times PS^T_{AS,P,i} \times t_i \times 0.8\right) + (VS^T_{avail,AS,P,i-1} - VS^T_{deg,AS,P,i-1}) \quad \text{(Equation 5.28)}$$

Where:

VS^T_i	=	Volatile solids produced by cattle type T on a dry matter basis during the reporting period i (kg cattle^{-1} day^{-1})
C^T_i	=	Average number of animals for each cattle type T during the reporting period i
$PS^T_{AS,P,i}$	=	Percent of manure solids sent to (managed in) anaerobic manure storage/treatment system AS from cattle type T during the reporting period i. Dairy-specific data must be used.[22]
t_i	=	Number of days in the reporting period i
0.8	=	System calibration factor[23]

[22] The value of PSAS,P,iT must take into account: the fraction of volatile solids that were recoverable (i.e., able to be collected for transfer into the anaerobic storage/treatment system), which is a function of the amount of time animals spent in different enclosure types; the type and efficiency the manure collection system; and the efficiency of the solid separation technology.
[23] From California Air Resources Board (2023) and US EPA (2016).

$VS^{T}_{avail,AS,P,i-1}$	=	Volatile solids from cattle type T from the previous reporting period $i - 1$ available for degradation in anaerobic storage/treatment system AS (kg dry matter).[24]
$VS^{T}_{deg,AS,P,i-1}$	=	Volatile solids from cattle type T that would have degraded during the previous reporting period $i - 1$ in anaerobic storage/treatment system AS in the absence of the project (kg dry matter).

$$VS^{T}_{i} = \left[DMI^{T} \times \left(1 - DE^{T}\right) + \left(UE^{T} \times DMI^{T}\right)\right] \times (1 - ASH^{T}) \quad \textit{(Equation 5.29)}$$

Where:

DMI^{T}	=	Dry matter intake of cattle type T in the reporting period (kg)
DE^{T}	=	Diet digestibility of the feed for cattle type T in the reporting period as a fraction of gross energy (**Table 5.3**) (%) Where DE is not available from primary data sources, projects may choose to use the Athian Dairy Total Digestible Nutrients Tool instead. Methodology for this tool is available as **Appendix C. Athian Dairy Total Digestible Nutrients Tool Methodology.**
UE^{T}	=	Urinary energy of cattle type T in the reporting period expressed as a fraction of gross energy (dimensionless). A default value of 4% is used for UE. This value can be reduced to 2% for cattle fed with 85 percent or more grain in their diet.
ASH^{T}	=	Ash content of feed for cattle type T in the reporting period (**Table 5.3**) (%)

DE and Ash are calculated as a weighted average using the data from **Table 5.3**. Project developers may provide alternative approaches to determine DE and Ash content of feed.

5.4.1.1.2 Project Manure Methane Emissions from Non-Anaerobic Storage/Treatment

$$CH^{T}_{4\,dry,\,P} = \sum_{S,T}(C^{T}_{i} \times VS^{T}_{i} \times PS^{T}_{S,P} \times MCF_{S} \times B^{T}_{0} \times \rho_{CH_4} \times t) \quad \textit{(Equation 5.30)}$$

Where:

C^{T}_{i}	=	Average number of animals for each cattle type T during the reporting period
VS^{T}_{i}	=	Volatile solids produced by cattle type T on a dry matter basis during the reporting period (from (**Equation** 5.11, kg cattle^{-1} day^{-1})
$PS^{T}_{S,P}$	=	Percent of manure solids sent to (managed in) non-anaerobic manure storage/treatment system S from cattle type T during the reporting period. This should take into account the amount of manure that was recoverable, what fraction of recoverable manure was moved into the treatment/storage system, and what fraction of solids was separated. Dairy-specific data must be used.[25]

[24] For the first reporting period of the project, if there are no site-specific data on the mass of volatile solids in the anaerobic storage/treatment system at the beginning of the project, the value may be calculated as described in Footnote 9. If the retention time for volatile solids in the anaerobic storage/treatment system is less than or equal to 30 days, set (VSavail,AS,P,i-1T- VSdeg,AS,P,i-1T) to zero. Similarly, for any reporting period following the complete drainage and cleaning of solid buildup from the anaerobic storage/treatment system, (VSavail,AS,P,i-1T- VSdeg,AS,P,i-1T) must be set to zero.

[25] The value of PSS,PT must take into account the fraction of volatile solids deposited on land (e.g., pasture, open lot) and the fraction that was recoverable (i.e., able to be collected for transfer into a non-anaerobic storage/treatment system). These fractions are functions of the amount of time animals would have spent on pasture vs. different enclosure types.

MCF_S	=	Methane conversion factor for non-anaerobic storage/treatment system S during the reporting period, based on T_2, in **Table 5.4**(%)
B_0^T	=	Maximum methane-producing capacity of manure for cattle type T in **Table 5.2** (m^3 CH_4 kg VS^{-1})
ρ_{CH_4}	=	Density of methane = 0.67 (1 atm, 60°F) (kg m^{-3})
t	=	Number of days in the reporting period

5.4.1.2 Project Manure Nitrous Oxide Emissions

Project emissions of N_2O are calculated as follows:

$$N_2O^T_{man,P} = \sum_T (N_2O^T_{dir,P} + N_2O^T_{ind,l,P} + N_2O^T_{ind,v,P}) \quad \text{(Equation 5.31)}$$

Where:

$N_2O^T_{dir,P}$	=	Direct N_2O emissions from management of manure from cattle type T in the reporting period (kg N_2O)
$N_2O^T_{ind,l,P}$	=	Indirect N_2O emissions from leaching of manure from cattle type T in the reporting period (kg N_2O)
$N_2O^T_{ind,v,P}$	=	Indirect N_2O emissions from cattle type T from the volatilization of NH_3 and NO_x in the reporting period (kg N_2O)

5.4.1.2.1 Project Direct N_2O Emissions from Manure Management

The calculation of direct N_2O emissions from the project 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 shall then be calculated using Equation 5.32:

$$N_2O^T_{dir,P} = (\sum_S(\sum_T(C^T \times N^T_{ex} \times AWMS_{S,TP}))) \times EF_{dir,S} \times \frac{44}{28} \quad \text{(Equation 5.32)}$$

Where:

C^T	=	Average number of animals for each cattle type T during the reporting period
N^T_{ex}	=	Average N excretion per animal of cattle type T (kg $head^{-1}$)
$EF_{dir,S}$	=	Emission factor for direct N_2O emissions from non-anaerobic manure management system S (**Table 5.5**) (dimensionless)
$\frac{44}{28}$	=	Conversion factor between $N_2O{-}N$ emissions and N_2O emissions
$AWMS_{S,TP}$	=	Project fraction of total annual volatile solids for each livestock category T that is managed in manure management system S.

PSS,PT also depends on the type and efficiency of the manure collection system in collecting recoverable manure and the efficiency of the solid separation technology.

5.4.1.2.2 Project Indirect N_2O Emissions from Leaching of Manure

The amount of nitrous oxide emitted from the project through leaching shall be calculated using Equation 5.33:

$$N_2O^T_{ind,l,P} = \sum_S(\sum_T(C^T \times N^T_{ex} \times AWMS_{S,TP} \times PL^T_S)) \times EF_l \times \frac{44}{28} \quad \text{(Equation 5.33)}$$

Where:

C^T	=	Average number of animals for each cattle type T during the reporting period
N^T_{ex}	=	Average N excretion per animal of cattle type T (kg head^{-1})
PL^T_S	=	Percent of managed manure nitrogen losses for cattle type T due to runoff and leaching during solid and liquid storage of manure in non-anaerobic manure management system S (see **Table 5.7**) (%)
EF_l	=	Emission factor for N_2O emissions from nitrogen leaching and runoff. The default value is 0.011 kg N_2O-N (kg N leaching/runoff)[26]
$\frac{44}{28}$	=	Conversion factor between $N_2O–N$ emissions and N_2O emissions
$AWMS_{S,TP}$	=	Project fraction of total annual volatile solids for each livestock category T that is managed in manure management system S.

5.4.1.2.3 Project Indirect N_2O Emissions from Volatilization of NH_3 and NO_x

The amount of nitrous oxide emitted from the project through volatilization in the forms of NH_3 and NO_x shall be calculated using Equation 5.34:

$$N_2O^T_{ind,v,P} = \sum_S(\sum_T(C^T \times N^T_{ex} \times AWMS_{S,TP} \times PV^T_S) \times EF_v \times \frac{44}{28} \quad \text{(Equation 5.34)}$$

Where:

C^T	=	Average number of animals for each cattle type T during the reporting period
N^T_{ex}	=	Average N excretion per animal of cattle type T (kg head^{-1})
PV^T_S	=	Percent of managed manure nitrogen for livestock type T that volatilizes as NH_3 and NO_x in non-anaerobic manure management system S (**Table 5.7**) (%)
EF_v	=	Emission factor for N_2O emissions from nitrogen volatilization. The default value is 0.010 kg N_2O-N (kg N leaching/runoff)[27]
$\frac{44}{28}$	=	Conversion factor between $N_2O–N$ emissions and N_2O emissions
$AWMS_{S,TP}$	=	Project fraction of total annual volatile solids for each livestock category T that is managed in manure management system S.

[26] Additional emission factors may be used from Table 11.3 in Chapter 11 of IPCC (2019).
[27] Additional emission factors may be used from Table 11.3 in Chapter 11 of IPCC (2019).

5.4.2 Project GHG Emissions from Electricity Use

Project GHG emissions from electricity consumption are calculated by multiplying the total quantity of electricity consumed for manure management activities by the emissions factor for electricity for the state in which the dairy is located, using Equation 5.35. In the absence of manure management-specific data, total electricity consumption for the dairy may be used.

$$GHG^{T}_{elec,P} = Elec^{T}_{P} \times EF_{elec} \times \frac{1}{2.2046} \qquad \text{(Equation 5.35)}$$

Where:

$GHG^{T}_{elec,P}$	=	GHG emissions from electricity use for manure management activities for cattle type T during the reporting period (kg CO_2)
$Elec^{T}_{P}$	=	Amount of electricity used for manure management activities for cattle type T during the reporting period (MWh)
EF_{elec}	=	Emissions factor for electricity in the state in which the dairy is located (lbs CO_2/MWh)[28]
2.2046	=	Conversion factor from lbs to kg

5.4.3 Project GHG Emissions from Fuel Use

GHG emissions from fuel use in the reporting period are calculated by multiplying the total quantity of each type of fuel used and the emissions factor for that type of fuel, then summing the terms. If manure management-specific data are not available, total fuel use for the dairy may be used.

$$GHG^{T}_{fuel,P} = \sum_{f}\left(Fuel^{T}_{f,P} \times EF_{fuel,f}\right) \qquad \text{(Equation 5.36)}$$

Where:

$GHG^{T}_{fuel,P}$	=	GHG emissions from fuel use for manure management activities for cattle type T during the reporting period (kg CO_2eq)
$Fuel^{T}_{f,P}$	=	Quantity of fuel of each fuel type f consumed in the reporting period for manure management activities for cattle type T (MMBtu or gallon)
EF_{f}	=	Fuel-specific emission factor (**Table 5.8**) (kg/MMBtu or kg/gal)

5.5 Fat and Protein Corrected Milk

Emissions factors shall be assessed against volume of Fat and Protein Corrected Milk (FPCM) per Equation 5.37 below. This protocol is not expected to have any impact on the volume of FPCM, however, baseline EF may still be compared to intervention EF for record keeping

[28] State-specific emissions factors are available via U.S. Energy Information Administration (2022). *US Electricity Profile 2021.* https://www.eia.gov/electricity/state/

purposes. It should be noted that this protocol addresses absolute emissions, not intensity emissions, and should have no effect on milk production.

$$FPCM = Milk\ x\ [01.226\ x\ Fat + 0.776\ x\ True\ Protein + 0.2534]^{29} \quad \text{(Equation 5.37)}$$

Where:

$FPCM$	=	Fat and Protein Corrected Milk during the reporting period (kg)
$Milk$	=	Quantity of milk generated during the reporting period (kg)
Fat	=	Fat content of milk generated during the reporting period (%)
$True\ Protein$	=	True Protein content of milk generated during the reporting period (%)

If the producer monitors milk protein as crude protein, rather than true protein, it shall be converted as follows:

$$True\ Protein = Crude\ Protein - 0.19 \quad \text{(Equation 5.38)}$$

Where:

$True\ Protein$	=	True Protein content of milk generated during the reporting period (%)
$Crude\ Protein$	=	Crude Protein content of milk generated during the reporting period (%)

5.6 Uncertainty

Quantitative uncertainty in both the model and variables has been assessed with a Monte Carlo simulation. This choice in technique was based on both Gold Standard and IPCC methodologies for assessing uncertainty and will be added in the form of a new addition to the final GHG reduction equation in the form of an uncertainty deduction. The uncertainties from the USDA's Quantifying Greenhouse Gas Fluxes Table 5.32 were used as the basis for the Monte Carlo simulation (See 0.) The method relies on known probability distributions for input variables and then uses those distributions to generate sets of sample input data to create a large volume of outputs that can then be modeled to show the distribution of the results against both the probability of that results occurrence and the frequency. The model itself identifies upper and lower bounds for each variable by each cattle type and using a simulated set of input data, identifies the degree of possible variation within those bounds and its effect on the final output.

The model created using the above methodologies was tested for 10,000 instances and the resultant uncertainty deduction that is to be applied to the results of Equation 5.1 is 56.21%.

[29] Calculated per International Dairy Federation Guidelines, 2022, Equation 1

5.7 Leakage & Permanence

A recent expert review determined that the standards on which this protocol is based are “limited to the portion of the cattle facilities where manure is stored, and animals are housed” and the experts "do not see potential for leakage.”[30] Because the activities in this protocol act to reduce the emissions of methane and nitrous oxide, the reductions in greenhouse gas emissions associated with the protocol are permanent and cannot be reversed, representing no threat to permanence.

6 Monitoring

This program is 100% monitoring. All producers participating in the program will go through verification of their baseline data and verification of monitoring periods. A monitoring plan has been developed for all monitoring and reporting activities associated with the project, standardized across all participating farms.

Verifiers will use the monitoring plan and report to confirm that the requirements of this program have been met. This monitoring plan provides the processes, requirements, and sources of information necessary to assess the GHG reductions created by the practices included in this protocol.

This includes:

1. The procedures for collecting data on intervention activities related to implementation.
2. The data points collected to verify emission reduction, project, and baseline calculations.
3. The QC/QA processes to ensure the accuracy and consistency of the data collected.

The monitoring reports described in the monitoring plan 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.

[30] Compliance Offset Protocol Task Force Final Recommendations, pg 151-152

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.

Monitoring periods represent one full calendar month in which the intervention was active on the farm. This is the preferred duration of a monitoring period and is the default within the Athian platform. Retroactive monitoring periods may represent a larger unit of time at the discretion of Athian, but go forward must be in calendar months.

When the monitoring period is over (i.e. the month or quarter has fully passed), data from operating records are input into the Athian quantification tool to assess the impact of the intervention for that monitoring period. Supporting documents are collected concurrently. Once all required inputs and supporting documentation is collected, a third-party verifier receives the information to assess the validity of the reported inputs as well as verify the quantification themself. Participating producers are given the opportunity to produce further documentation of any values the verifier determines to be non-compliant before a final decision on the results of the monitoring period is rendered, either verified or not.

This monitoring plan provides the requirements and sources of information necessary to assess the GHG reductions created by the use of alternative manure management practices (AMMP) on U.S. dairies. Alternative manure management reduces GHG emissions generated from manure degradation. This monitoring plan describes the procedures for collecting data on intervention activities related to the implementation of AMMP. The data collected will support emission reduction and baseline calculations. This monitoring plan also outlines the QC/QA processes to ensure the accuracy and consistency of the data collected that will be used to verify emissions reduction outcomes.

6.1 Data Quality

The Athian Data Quality Management Plan aims to ensure that a producer's data is accurate, reliable, and fit for its intended purpose to assess the impact of Alternative Manure Management practices on CO_2e emissions associated with the management of manure. The goals and objectives of a can be categorized into several key areas, each targeting different aspects of data quality management. These include accuracy, timeliness, comparability, and creditability.

Accuracy:

- Data Collection Methods: Data will be provided by the farm directly based on various on farm systems.
- Consistency Checks: Input forms will check for data type and range preventing grossly invalid data from being entered.
- Method Validation: Based on type, input may be limited to certain ranges or values. Additionally, producers must attest to and confirm accuracy.

Timeliness:

- Data Collection Frequency: As defined by the protocol
- Data Reporting Schedule: Specific schedules are defined by the protocol monitoring plan.
- Response Procedures for Data Variations: Significant data issues should be prevented at entry. Additionally identified issues can be corrected by Athian staff as needed.

Comparability:

- Standardized Methods Used: Form input is used to collect quantitative data from on farm systems.
- Benchmarking: Per the Athian Data Retention Policy, all GHG related data is kept for a minimum of 7 years. Data, in aggregated and anonymized form, can be used for benchmarking if/when applicable.

Creditability:

- Documentation of Data Processes: All data processes are ultimately governed by the Athian Data Protection, Data Retention, and Software Development Lifecycle (SDLC) policies. These policies are maintained as controlled documents in the Athian compliance system (Drata) and are reviewed and updated at least annually.
- Transparency Measures: Data transparency is critical to credibility and integral to the data collection process. Data input directly in the platform from producers requires an attestation from the producer as to the accuracy before being submitted for verification. Data collected via an integration to a 3rd party data collection software also requires the producer to attest to the accuracy. In addition, producers have visibility as to the data provided to 3rd party verifiers and can see the status of the verification of each element of data submitted. All verification reports include each data element collected and reviewed as part of the verification process for complete transparency in the reporting of the emissions result

The Athian platform has a comprehensive set of automated processes that confirm the integrity, correctness, and completeness of data. These include checking the data upon ingestion from any 3rd party data source, inclusive of data delivered via API or manually entered, for completeness and accuracy. These checks include verification of appropriate formatting, field-level requirements that ensure the presence of all required data, and identification of any data variance from the previously verified data. If errors are identified, notifications are generated and delivered to engineering, product management, and service management for resolution. Those parties then determine the source and scope of the issue(s), engage any necessary participating party, resolve and document the identified issues.

In addition to the data validation checks identified above, Athian has implemented a service-driven approach for applying logic consistently, significantly reducing the potential for error in the process. The programmatic logic used reduces or replaces much of the process that is prone to human error. The Athian platform hosts the mechanisms for documenting any data discrepancy as well as their respective severity and solution. The platform retains a complete transaction history for all data ingested, inclusive of date/time stamp and the individual user or software supplying the information. This ensures that Athian will have a complete history/picture of all data used when rendering a decision or result.

All data used to meet GHG carbon accounting standards for impact units must be retained for a minimum of seven years. This includes producer business contact information, location information, monitoring period information, and all verification information. For the purposes of tracking carbon asset usage, buyer information must also be retained for a minimum of seven years. All of the aforementioned processes and procedures adhere to industry best practices, including SOC 2 review. The quantification tool for this program is thoroughly tested against known results of data sets any time updates to the quantification methodology or tool are made. The tests follow the same methods as used for the Simulated AMMP Quantification Model and are checked against the quantification methodology for accuracy by the Athian development team.

Table 6.1 *Monitoring Parameters*

Data/ Parameter	Description	Data Unit	Data Source	Measurement Frequency	Values Applied	Measurement methods and procedures, including QA/QC	Roles and Responsible	Data Management
T	Type of cattle included in the project	Cattle type	Operating records	Every reporting period	Type of cattle	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
GWP_{CH4}	Global warming potential of methane	kg CO_2e kgCH_{4-1}	Reference	N/A	29.8	Constant	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool	Stored within the Athian platform and available as part of the published protocol.
GWP_{N2O}	Global warming potential of nitrous oxide	kg CO_2e kg N_2O^{-1}	Reference	N/A	273	Constant	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool	Stored within the Athian platform and available as part of the published protocol.
AS	Anaerobic storage/ treatment system	Type of treatment system	Operating records	At project start, and confirmed every reporting period	Name of system(s)	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
B_0^T	Maximum methane-producing capacity of manure for cattle type T	m^3 CH_4 kg VS^{-1}	Reference	N/A	Table 5.2	Constant	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored and available as part of the published protocol.

f_i	The van't Hoff-Arrhenius factor for the current reporting period $_i$	kg m^{-3}	Calculated	Every reporting period	Calculation based on temperature information for the current reporting period	N/A	Athian is responsible for ensuring this value is correctly calculated in their platform with regular checks of the quantification tool.	Data located in the Athian platform and available to producers and third-party verifiers.
T_2	Average ambient temperature in the reporting period	K	Obtained via API with the National Weather Service based on producer location	Every reporting period	Approx. 222 to 323 K	Obtained from the closest weather station within the air basin as reported by major weather outlets such as the National Weather Service.	Athian is responsible for ensuring this value is correctly brought into their platform with regular checks of the quantification tool.	The Athian platform is intended to interface with the National Weather Service to pull this information in its most accurate form for each monitoring period.
VS_i^T	Volatile solids produced by cattle type T on a dry matter basis during the reporting period i	kg $cattle^{-1}$ day^{-1}	Calculated	Every reporting period	Approx. 5.4 to 7.7	N/A	Athian is responsible for ensuring this value is correctly calculated in their platform with regular checks of the quantification tool.	Data located in the Athian platform and available to producers and third-party verifiers.
C_i^T	Average number of animals for each cattle type T during the reporting period i	Number of cattle	Operating records	Every reporting period	Number of cattle	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.

$PS_{AS,B,iT}$	Percent of manure solids that would have been sent to (managed in) anaerobic manure storage/treatment system AS from cattle type T during the reporting period i in the absence of the project.	%	Operating records	Every reporting period	0 to 100%	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
t_i	Number of days in the reporting period i	days	Measured	Every reporting period	≥28	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
DMI_T	Dry matter intake (DMI) of cattle type T	kg	Operating records	Every reporting period	Approx. 19 to 23	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
DE_T	Diet digestibility of cattle type T in the reporting period as a fraction of gross energy	%	Operating records or reference	Every reporting period	Table 5.3	Obtained from producer records If not available from operating records, then based on the information in Table 5.3	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.

UE_T	Urinary energy of cattle type T in the reporting period expressed as a fraction of gross energy	dimensionless	Reference	Every reporting period	A default value of 4% is used for UE. This value can be reduced to 2% for cattle fed with 85 percent or more grain in their diet.	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.
ASH_T	Ash content of feed for cattle type T in the reporting period	%	Reference	Every reporting period	Table 5.3	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.
S	Non-anaerobic manure storage/ treatment system	Type of treatment system	Operating records	Every reporting period	Name of treatment system. Listed in tables 5.4 and 5.5	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
VS_T	Volatile solids produced by cattle type T on a dry matter basis during the reporting period	kg $cattle^{-1}$ day^{-1}	Calculated	Every reporting period	Approx. 5.4 to 7.7	N/A	Athian is responsible for ensuring this value is correctly calculated in their platform with regular checks of the quantification tool.	Data located in the Athian platform and available to producers and third-party verifiers.

$PS_{S,BT}$	Percent of manure solids that would have been sent to (managed in) non-anaerobic manure storage/ treatment system S from cattle type T during the reporting period in the absence of the project.	%	Operating records	Every reporting period	0 to 100%	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
MCF_S	Methane conversion factor for storage/ treatment system S	%	Reference	Every reporting period	Table 5.4	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.
$EF_{dir,S}$	Emission factor for direct N_2O emissions from non-anaerobic manure management system S	dimensionless	Reference	Every reporting period	Table 5.5	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.
CP_T	Crude protein content in the overall diet	%	Operating records	Every reporting period	0 to 100%	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
M	Average milk production per cow during the reporting period	kg $head^{-1}$ day^{-1}	Operating records	Every reporting period	25 to 31	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.

M_p	Percentage of protein in the milk during the reporting period	%	Operating records	Every reporting period	0-100%	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
WG_T	Average weight gain of the animals in the population of cattle type T	kg day^{-1}	Reference	Every reporting period	Table 5.6-C	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.
BW_T	Average live body weight (BW) of the animals in the population of cattle type T	kg	Reference	Every reporting period	Table 5.6-B	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.
MW_T	Mature live body weight of an adult animal in moderate body condition	kg	Reference	Every reporting period	Table 5.6-A	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.
PL_{ST}	Percent of managed manure nitrogen losses for cattle type T due to runoff and leaching during solid and liquid storage of manure in non-anaerobic manure management system S	%	Reference	Every reporting period	Table 5.7 0 to 6%	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.

$EF_{(l)}$	Emission factor for N_2O emissions from nitrogen leaching and runoff.	kg N leaching/ runoff	Reference	Every reporting period	The default value is 0.011 kg N_2O-N.	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.
$EF_{(v)}$	Emission factor for N_2O emissions from nitrogen volatilization.	kg N leaching/ volatilization	Reference	Every reporting period	The default value is 0.010 kg N_2O-N.	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.
PV_{ST}	Percent of managed manure nitrogen for livestock type T that volatilizes as NH_3 and NO_x from non-anaerobic manure management system S	%	Reference	Every reporting period	Table 5.7	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.

$Elec_{BT}$	The average amount of electricity that would have been used for manure management activities for cattle type T in the absence of the project, based on average electricity consumption for the same time as the reporting period from the 2 years prior to the project start date.	MWh	Operating records	Every reporting period		Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
EF_{elec}	Emissions factor for electricity in the state in which the dairy is located	lbs CO_2 MWh^{-1}	Reference	Every reporting period	U.S. Energy Information Administration (2022). *US Electricity Profile 2021.* https://www.eia.gov/electricity/state/	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.

$Fuel_{BT}$	The average amount of fuel that would have been used for manure management activities for cattle type T in the absence of the project, based on average fuel consumption for the same time as the reporting period from the 2 years prior to the project start date	mmBtu or gallon	Operating records	Every reporting period		Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
$EF_{fuel, f}$	Fuel-specific emission factor	kg/mmBtu or kg/gal	Reference	Every reporting period	Table 5.8	N/A	Athian is responsible for ensuring this value is correct in their platform with regular checks of the quantification tool.	Stored within the Athian platform and available as part of the published protocol.
$PS_{AS,P,iT}$	Percent of manure solids sent to (managed in) anaerobic manure storage/ treatment system AS from cattle type T during the reporting period i.	%	Operating records	Every reporting period	0 to 100%	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.

$PS_{S,PT}$	Percent of manure solids sent to (managed in) non-anaerobic manure storage/treatment system S from cattle type T during the reporting period.	%	Operating records	Every reporting period	0 to 100%	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
$Elec_{PT}$	Amount of electricity used for manure management activities for cattle type T during the reporting period	MWh	Operating records	Every reporting period		Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
$Fuel_{PT}$	The average amount of fuel used for manure management activities for cattle type T in the reporting period	mmBtu or gallon	Operating records	Every reporting period		Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
MF	Percentage of fat in the milk during the reporting period	%	Operating records	Every reporting period	3.5 to 4.5	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.

$AWMS_{S,TB}$	Baseline fraction of total annual volatile solids for each livestock category T that is managed in manure management system S.	%	Operating records	Every reporting period	0 to 100	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.
$AWMS_{S,Tp}$	Project fraction of total annual volatile solids for each livestock category T that is managed in manure management system S.	%	Operating records	Every reporting period	0 to 100	Obtained from producer records	Producer: inputting these values and ensuring they are correct Verifier: corroborating values against documentation	Data located in the Athian platform and available to producers and third-party verifiers.

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. 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

8 Verification

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

Projects verified under this protocol will meet, at minimum, the auditing standard of limited 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:

- 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
- Demonstrated/documented subject matter expertise in the on-farm operations related to an approved protocol (e.g., Dairy Operations; Feed Lot Operations)
- Demonstrated/documented experience in a particular region or state where the verification will occur
- Monitoring conducted in accordance with the requirements of the relevant protocol
- 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 verifiers 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 verifier's ability to perform an independent verification. Every verifier must provide information about its organizational relationships, internal structures, and management systems for identifying potential COIs. Verifiers 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 verifier must develop a risk-based verification plan that considers the size and complexity of the project and the relevant sector, technology, and processes. The verifier must follow the following process:

1. Complete a COI evaluation. If there is a potential COI, the verifier 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 verifier
    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. Conduct, at minimum, one annual on-site visit to confirm practice implementation

5. Undertake a desk review of the data from the project.
6. Prepare a verification report that includes:
    a. A verification statement documenting the outcome of the assessment (reduction results) and if there was any material discrepancy noted
    b. Key details about the project including: producer and farm operation identification, verifying body and lead verifier contact information, protocol information, and intervention information
    c. A description of the protocol, the objectives and criteria used to arrive at the final result, the scope of the project, the level of assurance associated with the project, and any details about the implementation of the practices observed
    d. Detail about the verification process used to complete the assessment including approach and methods and also noting any conflict of interest
    e. Verification findings including confirmation of producer eligibility, adherence to the criteria established in the protocol, the verified emissions quantification values, and the final written opinion of the verifier(s)
    f. An issue log capturing any issues identified during the verification and their classification as either material (significant) or immaterial (insignificant)
    g. A representation of all data / documents used in the process of verification

9 Practice Definitions

Closed Solar Drying: Unlike open solar drying described above, closed solar drying involves putting manure into an enclosed container for its drying process. This improves the efficiency of drying and reduces the risk of leaching and runoff. In both practices, manure emissions are reduced through the drying of manure volatile solids.

Compost Bedded Pack Barn: Bedded pack barns are a loose housing system in which dairy cattle have an open area in which to rest, ruminate, and spend time, usually separated from the area where they eat and drink. The housing area (the pack) may be managed either aerobically or anaerobically. Anaerobic management includes the regular re-application of fresh bedding materials such as straw or sawdust without any aeration or turning. Aerobic or compost barns are stirred regularly (often multiple times a day) which helps with moisture and temperature control in the compost. Manure is deposited directly into the bedding material, which serves to distribute moisture evenly away from the manure solids and acts as additional dry matter for the compost build up in the pack system itself. Previously composted manure may also be used as the pack bedding material, often in conjunction with straw or sawdust to improve mixing.

Composting in Vessel: Composting is the decomposition of organic material in a managed system. Composting in a vessel controls the environment of the composting by containing it to a manageable space. The success of this practice in emissions reductions hinges on the forced aeration and/or mixing. These techniques not only help control the moisture content and microorganism load of the compost, but also regularly introduce oxygen to ensure a non-anaerobic environment for decomposition.

Composting in Windrows: As with composting in vessels, composting in windrows is the decomposition of organic material in a managed system. This particular style of composting builds up lines of compostable material for this degradation. Exposure to the elements and the sun helps ensure a non-anaerobic environment for this degradation, however additional mixing and aeration may be used as well.

Conversion From A Flush To Scrape Manure Collection System: A flush system involves the use of water to regularly flood concrete lanes in a barn (“flushing” them) to remove manure, urine, and other debris that may have accumulated. This flush then travels into a containment area, a lagoon, for breakdown. The addition of water to this system ensures an anaerobic environment for the manure solids once they do reach that containment area unless the solids are first separated out. A scrape system, in contrast, uses equipment such as tractors or an automated version attached to a tether and motor to remove manure from the lanes. These systems introduce less overall moisture to the manure solids and when used in conjunction with a solid separation practice from the list below, result in a reduced amount of manure solids that are managed anaerobically.

Daily Spread: Daily spread involves the removal of manure from the confinement facility and direct land application within 24 hours. This practice diverts manure solids from anaerobic conditions in lagoons, but may also have some of the benefits of solar drying in further separating the liquids from the manure solids.

Forced Evaporation With Natural Gas Fueled Dryers: Much like solar drying, this practice relies on the separation of manure solids and liquids to reduce the amount of solids managed anaerobically. These dryers force heated air into contact with the manure, drying it out more quickly than in the solar drying options.

Open Solar Drying: This practice relies on the use of passive solar energy to remove moisture from the manure. Manure is spread out in a layer over a space where it can get sufficient sun exposure to dry it out before being moved elsewhere for either composting or land application. In both solar drying practices, manure emissions are reduced through the drying of manure volatile solids. This practice also applies to dry lot housing.

Pasture-Based Management: Managing dairy animals on pasture instead of in confinement facilities allows for emissions reductions in several ways. Manure is applied to the land directly immediately upon excretion, diverting it from anaerobic degradation. On pasture, the manure is spread out, aerating it, by the movement of animals as well as environmental factors. This exposes the manure further to oxygen. Additionally, sun exposure increases the rate of drying on land, further separating the manure solids from the liquids, ensuring non-anaerobic degradation.

Slatted Floor Pit Storage: In a slatted floor pit storage facility, cattle are housed over a floor with openings into a storage container beneath the barn itself. The manure is stored in this space for 30 days or less, after which it is cleaned out. While this storage method does not involve separation of liquids and volatile solids, which does create an anaerobic environment, the regular cleaning greatly reduces the build-up of volatile solids that might completely degrade in this anaerobic environment as opposed to a large lagoon. After the cleaning takes place, the manure may be relocated for compost or for direct land application.

Solid Separation Of Manure Solids Before Being Deposited Into An Anaerobic Environment: Solid separation technologies include but are not limited to weeping walls, stationary screens, vibrating screens, screw presses, centrifuges, roller drums, belt presses/screens, advanced solid-liquid separation assisted by flocculants and/or bead filters, and vermifiltration.

Solid Separation With An Aerated Vermifiltration System: Vermifiltration uses a filter system of several layers, the topmost of which is earthworms in a combination of soil and vermicompost. This layer aids in the separation of manure solids and liquids in the same way as the vermicomposting does, and the resultant by-products may be used in compost and agricultural applications. This method, like the other solid separation methods, diverts manure solids from anaerobic degradation into an aerobic system, where the worms assist in the aeration of the manure while in the filter.

Solid Storage: This practice involves the storage of manure in unconfined piles or stacks, diverting manure from liquid storage in a lagoon. These stacks must be cleaned out with some regularity to ensure the minimization of anaerobic storage. From this storage, manure may be added to compost or spread on cropland or pasture.

10 References

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Appendix A. **Table of Variable References**

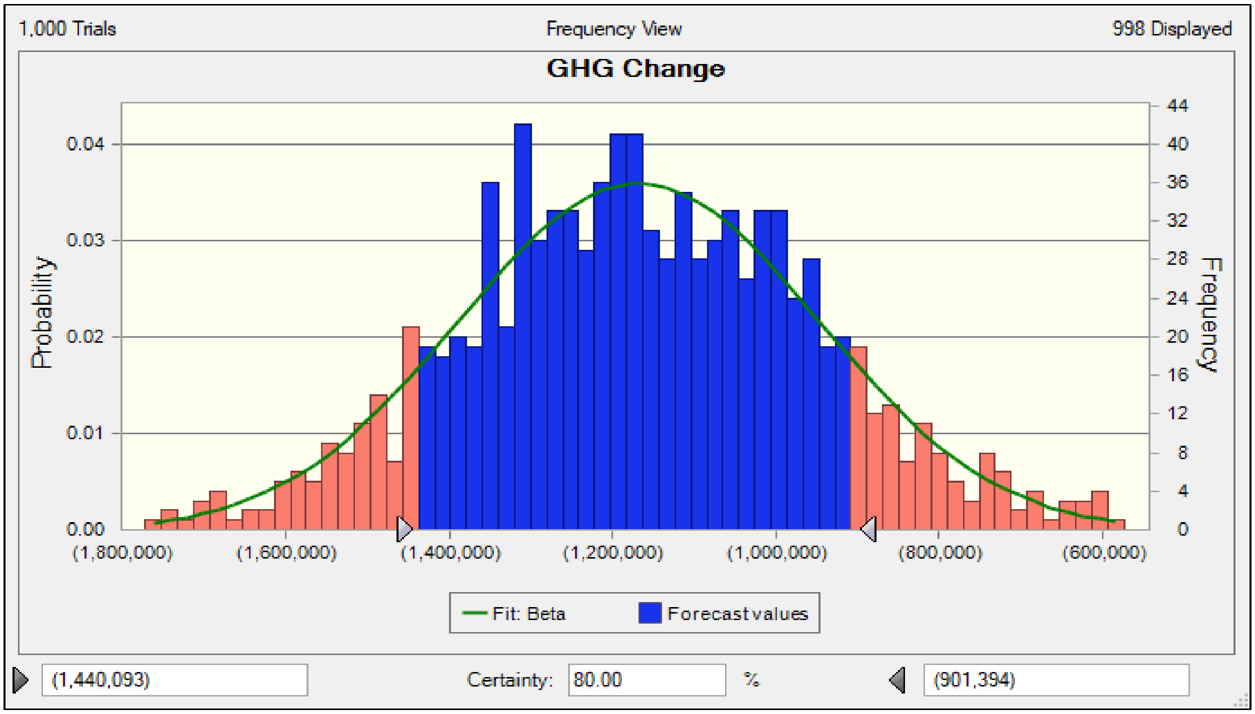
Variable	Definition	Source of Data
ASH(T)	Ash content of feed for cattle type T in the reporting period (see Table 5.3) (%)	Taken from Appendix 5-B of Powers et al. 2014. Additional feed values are available in the Powers Appendix.
B(T0)	Maximum methane-producing capacity of manure for cattle type T (see Table 5.2, m3 CH4 kg VS-1)	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
BW(T)	Average live body weight (BW) of the animals in the population of cattle type T in kg	Table 10A.1 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
DE(T)	Diet digestibility of the feed for cattle type T in the reporting period as a fraction of gross energy (see Table 5.3) (dimensionless)	Taken from Appendix 5-B of Powers et al. 2014. Additional feed values are available in the Powers Appendix.
EF(dirS)	Emission factor for direct N2O emissions from non-anaerobic manure management system S (dimensionless) in Table 5.5.	Adapted from Table 10.21 in Chapter 10 of IPCC (2019).
EF(elec)	Emissions factor for electricity in the state in which the dairy is located (lbs CO2/MWh)	State-specific emissions factors are available via U.S. Energy Information Administration (2022). US Electricity Profile 2021. https://www.eia.gov/electricity/state/
EF(fuel,f)	Fuel-specific emission factor (kg/mmBtu or kg/gal)	Values calculated from data in U.S. Environmental Protection Agency. (2014). Emissions Factors for Greenhouse Gas Inventories. https://www.epa.gov/sites/default/files/2015-07/documents/emission-factors_2014.pdf using GWPCH4 = 29.8 and GWPN2O = 273 (Forster et al. 2021).
EF(l)	Emission factor for N2O emissions from nitrogen leaching and runoff.	Table 11.3 in Chapter 11 of IPCC (2019).
EF(V)	Emission factor for N2O emissions from nitrogen volatilization (kg N leaching/runoff)	Table 11.3 in Chapter 11 of IPCC (2019).
GWP(CH4)	Global warming potential of methane (kgCO2e kgCH4-1)	100-year time horizon; Chapter 7 of IPCC Sixth Assessment Report (Forster et al. 2021)
GWP(N2O)	Global warming potential of nitrous oxide (kg CO2e kg N2O-1)	100-year time horizon; Chapter 7 of IPCC Sixth Assessment Report (Forster et al. 2021)
MCF(S)	Methane conversion factor for non-anaerobic manure storage/treatment system S during the reporting period, based on T2, in Table 5.4 (%)	Values from CDFA (2023) AMMP Draft Benefits Calculator Tool.
MW(T)	Mature live body weight of an adult animal of cattle type T in moderate body condition in kg, either from producer records or using defaults	Based on 2018-2020 USDA NASS mean cow slaughter weight, assuming dressing % of 50%
N(Tex)	Average N excretion per animal of cattle type T (kg head-1)	Equation 10.31A in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

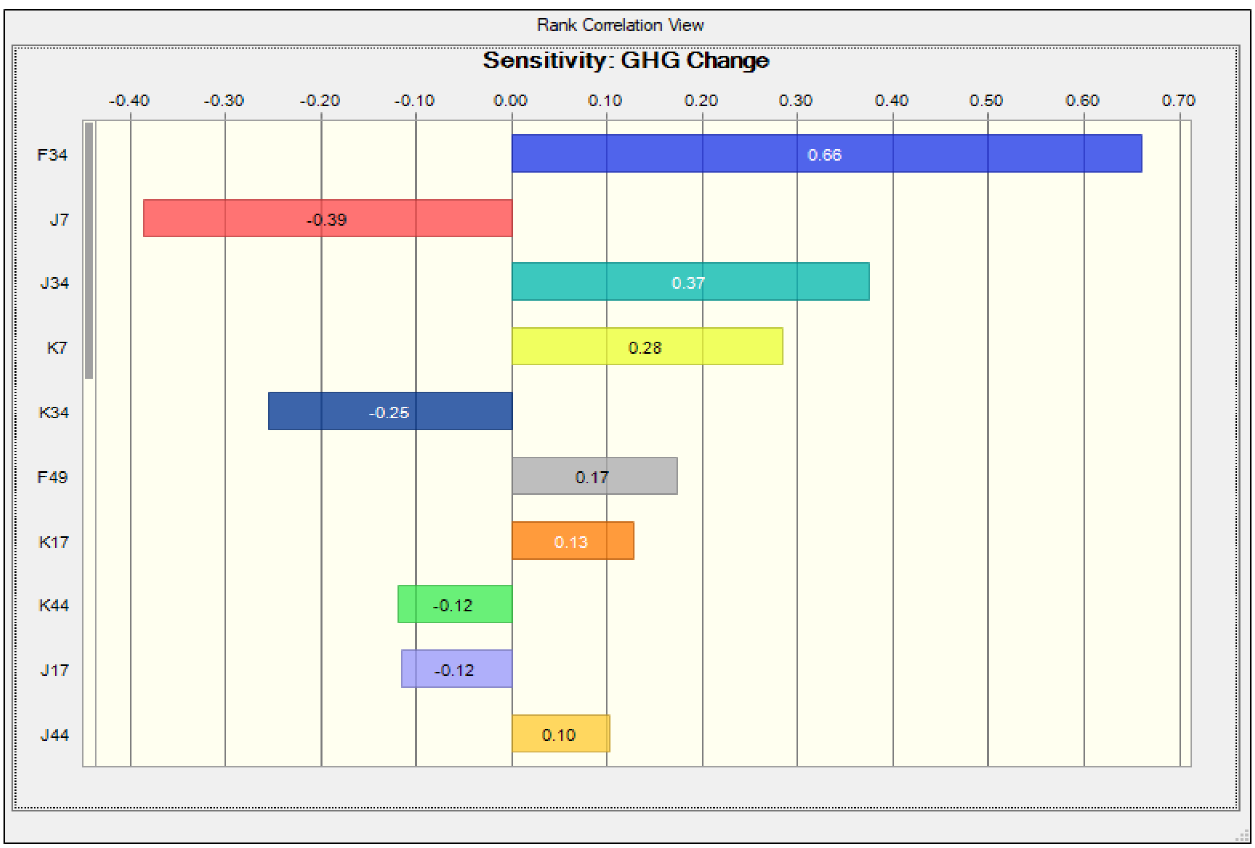
N(Tin)	Average daily nitrogen intake per animal of cattle type T in the reporting period (kg head-1 day-1)	35 Equation 10.32 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas, Inventories
N(Tret)	Fraction of daily N intake that is retained by cattle type T (dimensionless).	Equation 10.33 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories
NE(G)	Net energy for growth (MJ day-1)	Equation 3-8 in NRC (1996)
PL(TS)	Percent of managed manure nitrogen losses for cattle type T due to runoff and leaching during solid and liquid storage of manure in non-anaerobic manure management system S (%)	From Table 10.22 in Chapter 10 of IPCC (2019).
PV(TS)	Percent of managed manure nitrogen for livestock type T that volatilizes as NH3 and NOx from non-anaerobic manure management system S	From Table 10.22 in Chapter 10 of IPCC (2019).
RCH4	Density of methane	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
SCF	System calibration factor	From California Air Resources Board (2023) and US EPA (2016)
UE(T)	Urinary energy of cattle type T in the reporting period expressed as a fraction of gross energy (dimensionless).	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
WG(T)	Average weight gain of the animals in the population of cattle type T (kg day-1)	Table 10A.1 in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Appendix B. Uncertainty Deduction Model

Quantitative uncertainty in both the model and variables has been assessed with a Monte Carlo simulation. This choice in technique was based on both Gold Standard and IPCC methodologies for assessing uncertainty and will be added in the form of a new addition to the final GHG reduction equation in the form of an uncertainty deduction. Please see Section 5.6 for additional information.

Herd Description By Cattle Type	
Lactating (freestall)	1,000
Lactating (open lot)	-
Dry dairy cows	300
All other types	300
Emission Reduction (Herd - Kg CO2e)	
Expected Reduction (ET_0)	1,168,089
Uncertainty Percentile Boundaries:	
10th Percentile	(1,440,093)
90th Percentile	(901,394)
Uncertainty Deduction From Calculated Estimate	
Total Kg CO_2e Uncertainty Deduction (UNC)	0.56
90 % Confidence Uncertainty Deduction (UD)	656,583
GHG Emission Credits After Deduction	
Kg CO_2e	511,506
MT CO_2e	512


1,000 Trials
Frequency View
998 Displayed
GHG Change
Probability
Frequency
0.04
0.03
0.02
0.01
0.00
44
40
36
32
28
24
20
16
12
8
4
0
(1,800,000)
(1,600,000)
(1,400,000)
(1,200,000)
(1,000,000)
(800,000)
(600,000)
Fit: Beta
Forecast values
(1,440,093)
Certainty: 80.00 %
(901,394)


Rank Correlation View
Sensitivity: GHG Change
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-0.30
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
F34
0.66
J7
-0.39
J34
0.37
K7
0.28
K34
-0.25
F49
0.17
K17
0.13
K44
-0.12
J17
-0.12
J44
0.10

Appendix C. Athian Dairy Total Digestible Nutrients Quantification Methodology

The methodology below was developed in conjunction with nutrition resources to determine the most streamlined methods with minimal data requirements from producers. There are two different calculation paths: one for lactating cattle and one for dry cows and heifers.

The Athian Dairy Total Digestible Nutrients Tool Methodology has been reviewed by the Athian Scientific Advisory Board and approved for use in this validated protocol.

Methodology for Lactating Cows

The lactating cattle methodology is based on the energy needs for maintenance and production of the lactating animals.

Total Digestible Nutrients[31]

$$TDN = (DE_{intake}/0.0441)/100 \quad \text{(Equation 39)}$$

Where:

TDN	=	Total digestible nutrients (%)
DE_{intake}	=	Dietary energy intake (Mcal/kg DMI), calculated per Equation 40.

Dietary Energy Intake

$$DE_{intake} = ME_{intake}/0.82 \quad \text{(Equation 40)}$$

Where:

ME_{intake}	=	Metabolizable energy intake (Mcals/kg DMI), calculated per Equation 41.
0.82	=	Conversion factor from ME to DE[32]

Metabolizable Energy Intake

$$ME_{intake} = ME_{req}/DMI_T \quad \text{(Equation 41)}$$

[31] NASEM 2001, Equation 2-1
[32] NRC 1996 via NASEM 2001, page 17

Where:

ME_{intake}	=	Metabolizable energy intake (Mcals/kg DMI), calculated per Equation 41.
ME_{req}	=	Total required metabolizable energy (Mcals/day), calculated per Equation 42.
DMI_T	=	Dry matter intake of cattle type T (kg/hd/day)

Total Metabolizable Energy Required

$$ME_{req} = ME_{maint} + RE + ME_{lact} + ME_{growth} \quad \text{(Equation 42)}$$

Where:

ME_{req}	=	Total required metabolizable energy (Mcals/day), calculated per Equation 42.
ME_{maint}	=	Metabolizable energy for maintenance (Mcals/day), calculated per Equation 44.
RE	=	Retained energy (Mcals/day), calculated per Equation 52. *Note: for lactating animals, this value is set to 0.*
ME_{lact}	=	Metabolizable energy for lactation (Mcals/day), calculated per Equation 43.
ME_{growth}	=	Metabolizable energy for growth (Mcals/day), calculated per Equation 53. *Note: for lactating animals this value is set to 0.*

Metabolizable Energy for Lactation[33]

$$ME_{lact} = NE_{milk}/0.66 \quad \text{(Equation 43)}$$

[33] NASEM 2001, page 79

Where:

ME_{lact}	=	Metabolizable energy for lactation (Mcals/day), calculated per Equation 43.
NE_{milk}	=	Net energy requirements for milk production (total Mcals/hd/day), calculated per Equation 45.

Metabolizable Energy for Maintenance[34]

$$ME_{maint} = BW^{0.75} \text{ x } 0.1 \qquad \textit{(Equation 44)}$$

Where:

ME_{maint}	=	Metabolizable energy for maintenance (Mcals/day), calculated per Equation 44.
BW	=	Body weight (kg). See Table 1 for average live body weights by cohort.

Table C.1. Average Live Body Weights by Cohort[35]

Cohort	Body Weight (kg)	Source
Lactating cows	650 kg	Derived from IPCC guidance from 2019
Dry cows	650 kg	Derived from IPCC guidance from 2019
Heifers	400 kg	Derived from IPCC guidance from 2019

Net Energy for Milk Production[36]

$$NE_{milk} = (Fat \text{ x } 9.29) + (Protein \text{ x } 5.5) + (Lactose \text{ x } 3.95) \qquad \textit{(Equation 45)}$$

Where:

[34] NASEM 2021, Equation 3-13
[35] Consistent with Table 5.6-B from the validated Alternative Manure Management Protocol
[36] NASEM 2021, Equation 3-14a

NE_{milk}	=	Net energy requirements for milk production (total Mcals/hd/day), calculated per Equation 45.
Fat	=	Milk fat content (kg fat/kg milk)
$Protein$	=	Milk protein crude content (kg crude protein/kg milk)
$Lactose$	=	Milk lactose content (kg lactose/kg milk), calculated per Equation 46.

Milk Lactose Content

$$Lactose = M \text{ x } 0.0485 \quad \text{(Equation 46)}$$

Where:

$Lactose$	=	Milk lactose content (kg lactose/kg milk), calculated per Equation 46.
M	=	Reported milk production (kg/hd/day). Note: reported milk production will most commonly be reported in lbs/hd/day and must be converted into kg.
0.0485	=	Estimated lactose content of milk (%)[37]

Methodology for Dry Cows and Heifers

Total Digestible Nutrients[38]

$$TDN = (DE_{intake}/0.0441)/100 \quad \text{(Equation 47)}$$

Where:

TDN	=	Total digestible nutrients (%)

[37] NASEM 2021, page 102
[38] NASEM 2001, Equation 2-1

DE_{intake}	=	Dietary energy intake (Mcal/kg DMI), calculated per Equation 48.

Dietary Energy Intake

$$DE_{intake} = ME_{intake}/0.82 \quad \text{(Equation 48)}$$

Where:

ME_{intake}	=	Metabolizable energy intake (Mcals/kg DMI), calculated per Equation 49.
0.82	=	Conversion factor from ME to DE[39]

Metabolizable Energy Intake

$$ME_{intake} = ME_{req}/DMI_T \quad \text{(Equation 49)}$$

Where:

ME_{intake}	=	Metabolizable energy intake (Mcals/kg DMI), calculated per Equation 49.
ME_{req}	=	Total required metabolizable energy (Mcals/day), calculated per Equation 50.
DMI_T	=	Dry matter intake of cattle type T (kg/hd/day)

Total Metabolizable Energy Required

$$ME_{req} = ME_{maint} + RE + ME_{lact} + ME_{growth} \quad \text{(Equation 50)}$$

Where:

[39] NRC 1996 via NASEM 2001, page 17

ME_{req}	=	Total required metabolizable energy (Mcals/day), calculated per Equation 50.
ME_{maint}	=	Metabolizable energy for maintenance (Mcals/day), calculated per Equation 51.
RE	=	Retained energy (Mcals/day), calculated per Equation 52. *Note: for lactating animals, this value is set to 0.*
ME_{lact}	=	Metabolizable energy for lactation (Mcals/day), calculated per Equation 2.5.
ME_{growth}	=	Metabolizable energy for growth (Mcals/day), calculated per Equation 2.15. *Note: for lactating animals this value is set to 0.*

Metabolizable Energy for Maintenance[40]

$$ME_{maint} = BW^{0.75} \text{ x } 0.1$$ *(Equation 51)*

Where:

ME_{maint}	=	Metabolizable energy for maintenance (Mcals/day), calculated per Equation 51.
BW	=	Body weight (kg). See Table 1 for average live body weights by cohort.

Retained Energy[41]

$$RE = 0.0635 \text{ x } BW^{0.75} \text{ x } ADG^{1.097}$$ *(Equation 52)*

[40] NASEM 2021, Equation 3-13
[41] NASEM 2001, page 320. This equation was chosen over Equation 10-5 in NASEM 2021 to streamline data collection processes for producers.

Where:

RE	=	Retained energy (Mcals/day), calculated per Equation 52. *Note: for lactating animals, this value is set to 0.*
BW	=	Body weight (kg). See Table C.1 for average live body weights by cohort.
ADG	=	Expected average daily gain (kg/hd/day). Default for dry cows is 0.17[42] and default for heifers is 0.55[43].

Metabolizable Energy for Growth[44]

$$ME_{growth} = RE/0.4 \quad \text{(Equation 53)}$$

Where:

ME_{growth}	=	Metabolizable energy for growth (Mcals/day), calculated per Equation 53. *Note: for lactating animals this value is set to 0.*
RE	=	Retained energy (Mcals/day), calculated per Equation 52. *Note: for lactating animals, this value is set to 0.*

[42] NASEM 2021, page 223, average of range
[43] NASEM 2021, page 516, average of range
[44] NASEM 2021, Equation 11-7

Appendix D. Version History

Version	Approved Date	Approval Type	Material Changes
1.0	September 20, 2024	Validation	N/A
1.1	December 3, 2025	Annual Review	Updates for: -Clarifying baseline definition -Addition of the acceptable use of TDN instead of DE and Appendix C. Athian Dairy Total Digestible Nutrients Methodology -Update of emission factor from ECM to FPCM -Standardization of most current Athian language for verification process, data QA/QC, and monitoring plan language.