Anaerobic Digester and Cap and Flare Protocol for Dairy

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PRO-00000005	1.0	January 2025

Athian

Acknowledgements

This protocol is derived from AMS-III.D: Small-Scale Methodology: Methane Recovery in Animal Manure Management Systems Version 21.0. The AMS-III.D protocol was originally developed under the Clean Development Mechanism (CDM). This was adapted for use under the Athian Governance program, in conjunction with the Athian Alternative Manure Management Protocol, with approval from the Athian Scientific Advisory Board.

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1 Introduction

This methodology covers project activities involving the replacement or modification of anaerobic animal manure management systems in livestock farms to achieve methane recovery and destruction by flaring/combustion or gainful use of the recovered methane.

2 Project Definition

When volatile manure solids are stored in anaerobic conditions, a significant amount of methane is produced. When these conditions exist at a dairy facility that implements one of the practices included in this protocol, the facility can generate credits that can be sold to organizations looking to reduce their GHG 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 these conditions exist at a dairy facility that implements one of the practices included in this protocol, the facility can generate credits 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.

Typical projects include the replacement, modification, or continued operation of existing anaerobic manure management systems in livestock farms to achieve methane recovery and destruction by flaring/combustion or energetic use of the recovered methane.

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

This methodology is only applicable under the following conditions:

1. Animals included in the project located on a dairy operation
2. Animal types included; lactating and dry cattle and heifers
3. Evidence the dairy farm is located in the US or US Tribal Lands
4. The livestock population in the farm is managed under confined conditions;
5. Manure or the streams obtained after treatment are not discharged into natural water resources (e.g. river or estuaries);

6. The annual average temperature of baseline site where anaerobic manure treatment facility is located is higher than 5°C;
7. 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 1 m;
8. No methane recovery and destruction by flaring or combustion for gainful use takes place in the baseline scenario.

The project activity shall satisfy the following conditions:

1. The residual waste from the animal manure management system shall be handled non-anaerobically per the practices detailed in the Alternative Manure Management Appendix A.
2. Technical measures shall be used (including a flare for exigencies) to ensure that all biogas produced by the digester is used or flared;
3. The storage time of the manure after removal from the animal barns, including transportation, should not exceed 45 days before being fed into the anaerobic digester. If the project proponent can demonstrate that the dry matter content of the manure when removed from the animal barns is larger than 20%, this time constraint will not apply.
4. Projects that recover methane from landfills are excluded from this protocol. Projects for composting of animal manure shall use AMMP protocol. Project activities involving co-digestion of animal manure and other organic matters is excluded from this protocol.
5. Utilization of the recovered biogas is also eligible under this methodology. If the recovered biogas is used to power auxiliary equipment of the project activity, it should be taken into account accordingly, using zero as its emission factor; however, energy used for such purposes is not eligible for credits under this protocol.
6. New facilities and project activities involving capacity additions compared to the baseline scenario are only eligible if they comply with the related and relevant requirements protocol.
    a. Capacity addition: Project activities involving capacity increase may use this methodology provided that they can demonstrate that the most plausible baseline scenario for the additional (incremental) capacity is the baseline provided in the protocol. This demonstration shall include the assessment of alternatives to the project activity.
7. For project activities that seek to retrofit or modify existing units or equipment, the baseline may refer to the characteristics (i.e. emissions, efficiency) of the existing unit or equipment only to the extent that the project activity does not increase capacity or output or level of service unless detailed specifications are provided as part of the applied methodology. For any increase of capacity or output or level of service beyond this range due to the project activity, a different baseline shall apply.

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 and an attestation that the project activities do not cause material violations of applicable laws (e.g. water quality, safety, etc.). 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. 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 protocol.

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 may be increased or decreased by the practices included in this protocol. Electricity emissions are CO_2 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 5.13. 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 GHG Emission Reduction

The emission reductions achieved by the project activity will be determined ex post through direct measurement of the amount of methane fueled, flared, or gainfully used. Project activities must demonstrate or document regular calibration of the direct measurement equipment per manufacturer's instructions throughout the duration of the project. It is likely that the project activity involves manure treatment steps with higher methane conversion factors (*MCF*) than the *MCF* for the manure treatment systems used in the baseline situation, therefore the emission reductions achieved by the project activity are limited to the ex post calculated baseline emissions minus the project emissions using the actual monitored data for the project activity (i.e. $C_{T,i}$, $PS_{T,S,p,i}$, AI_S, as well as $VS_{T,i}$ in cases where adjusted values for animal weight are used). The emission reductions achieved in any reporting period are the lowest value of the following:

$$\Delta GHG_i = min\left[(GHG_B - GHG_P), \left(MD_i - GHG_{power,i}\right)\right] \quad \text{(Equation 5.1)}$$

Where:

ΔGHG_i	=	Emission reductions achieved by the project activity based on monitored values for reporting period *i* (t CO_2e)
GHG_B	=	Baseline emissions calculated using Equation 5.4 using monitored values of $C_{T,i}$ and if applicable $VS_{T,i}$.
GHG_P	=	Project emissions calculated using Equation 5.9 using monitored values of $C_{T,i}$, $PS_{T,S,p,i}$, AI_S, *and* if applicable $VS_{T,i}$
MD_i	=	Methane captured and destroyed or used gainfully by the project activity in reporting period *i* (t CO_2e)
$GHG_{power,i}$	=	Emissions from the use of fossil fuel or electricity for the operation of the installed facilities based on monitored values in the reporting period *i* (t CO_2e)

Biogas flared or combusted, *(MD_i)* shall be determined using the flare efficiency and methane content of biogas.

$$MD_i = BG_{burnt,i} \times w_{CH4,i} \times \rho_{CH4} \times FE \times GWP_{CH4} \quad \text{(Equation 5.2)}$$

Where:

MD_i	=	Methane captured and destroyed or used gainfully by the project activity in reporting period *i* (t CO_2e)
$BG_{burnt,i}$	=	Biogas flared or combusted in reporting period *i* (m^3)
$w_{CH4,i}$	=	Methane content in biogas in the reporting period *i* (volume fraction)
ρ_{CH4}	=	CH_4 density (0.00067 t/m3 at room temperature (20°C) and 1 atm pressure)
FE	=	Flare efficiency in the reporting period *i* (fraction)
GWP_{CH4}	=	Global warming potential of methane (kgCO_2e kgCH_4^{-1})

The method for integration of the terms in equation above to obtain the results for one monitoring period of measurements within the confidence level, as well as the methods and instruments used for metering, recording and processing the data obtained, shall be described in the project design document and monitored during the crediting period.

Alternatively, if project activities utilize the recovered methane for power generation, *MD_i* may be calculated as follows, based on the amount of monitored electricity generation, without monitoring methane flow and concentration:

$$MD_i = \frac{EG_i \times 3600}{NCV_{CH4} \times EE_i} \times \rho_{CH4} \times GWP_{CH4} \quad \text{(Equation 5.3)}$$

Where:

MD_i	=	Methane captured and destroyed or used gainfully by the project activity in reporting period *i* (t CO_2e)
EG_i	=	Total electricity generated from the recovered biogas in reporting period *i* (MWh)
3600	=	Conversion factor (1 MWh = 3600 MJ)
NCV_{CH4}	=	Net Calorific Value of methane (MJ/Nm^3) (use default value: 35.9 MJ/Nm^3)
EE_i	=	Energy conversion efficiency of the project equipment, which is determined by adopting one of the following criteria: ● Specification provided by the equipment manufacture. The equipment shall be designed to utilize biogas as fuel, and efficiency specification is for this fuel. If the specification provides a range of efficiency values, the highest value of the range shall be used for the calculation ● Default efficiency of 40 %.
ρ_{CH4}	=	CH_4 density (0.00067 t/m3 at room temperature (20°C) and 1 atm pressure)
GWP_{CH4}	=	Global warming potential of methane (kgCO_2e kgCH_4^{-1})

Project proponents shall provide evidence to a verifier that only the biogas recovered through the project manure management system is used for power generation; no other gas or fuels except a start-up fuel are used.

Project activities where a portion of the biogas is destroyed through flaring and the other portion is used for energy may consider applying the flare efficiency to the portion of the biogas used for energy, if separate measurements of the respective flows are not performed. When the amount of methane that is combusted for energy and that is flared is separately monitored, or when only the biogas flow to the flare is monitored and the biogas used for energy is calculated based on electricity generation, a destruction efficiency of 100% can be used for the amount that is combusted for energy.

Where applicable, reference the Athian AMMP protocol requirements.

5.2 Baseline GHG Emissions

The baseline scenario is the situation where, in the absence of the project activity, animal manure is left to decay anaerobically within the project boundary and methane is emitted to the atmosphere.

$$GHG_B = \sum_T \left(GHG^T_{man,B} + GHG^T_{elec,B} + GHG^T_{fuel,B}\right) \qquad \text{(Equation 5.4)}$$

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

5.2.1 Baseline GHG Emissions from Manure Management

Baseline emissions from manure management ($GHG_{T,man,B}$) are calculated by using the amount of the waste or raw material that would decay anaerobically in the absence of the project activity, with the most recent Athian Alternative Manure Management approach. For this calculation, information about the characteristics of the manure and of the management systems in the baseline is required. Manure characteristics include the amount of volatile solids (*VS*) produced by the livestock and the maximum amount of methane that can be potentially produced from that manure (B_0);

$$GHG^T_{man,B} = GWP_{CH4} \times \rho_{CH4} \times UD_B \times \sum_{S,T}\left(MCF_S \times B^T_0 \times C^T_i \times VS^T_i \times PS^T_{S,B} \times nd_i\right) \qquad \text{(Equation 5.5)}$$

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
GWP_{CH4}	=	Global warming potential of methane (kgCO_2e kgCH_4^{-1})
ρ_{CH4}	=	CH_4 density (0.00067 t/m3 at room temperature (20°C) and 1 atm pressure)
UD_B	=	Model correction factor to account for model uncertainties (0.94)[1]
T	=	Index for all types of cattle
S	=	Index for animal manure management system
MCF_S	=	Methane conversion factor (*MCF*) for the baseline animal manure management system *S*
B_0^T	=	Maximum methane producing potential of the volatile solid generated for cattle type *T* (m^3 CH_4/kg-dm)
C_i^T	=	Average number of animals of type *T* in reporting period *i* (numbers)
VS_i^T	=	Volatile solids production/excretion per head of cattle type *T* in reporting period *i* (on a dry matter weight basis, kg-dm/animal/day), using Equation 5.6
$PS_{S,B}^T$	=	Fraction of manure handled in baseline animal manure management system *S* by cattle type *T*
nd_i	=	Number of days treatment plant was operational in reporting period *i*

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)

Table 5.2 *Maximum Methane-producing Capacity of Manure for Cattle*[2]

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

[1] Reference: FCCC/SBSTA/2003/10/Add.2, page 25.
[2] Table from Table 5-19 of Powers et al. 2014.

5.2.2 Baseline Volatile Solids Produced

VS are the organic material in livestock manure and consist of both biodegradable and non-biodegradable fractions. For the calculations the total *VS* excreted by each animal species is required. Volatile solids can be calculated using Equation 5.6 below.

$$VS_i^T = \left[GE_T \times \left(1 - \frac{DE_T}{100}\right) + (UE_T \times GE_T)\right] \times \left[\left(\frac{1 - ASH_T}{ED_T}\right)\right] \quad \text{(Equation 5.6)}$$

Where:

VS_i^T	=	Volatile solid excretions for cattle type *T* entering all animal waste management systems on a dry matter weight basis (kg-dm/animal/day)
GE_T	=	Daily average gross energy intake (MJ/animal/day)
DE_T	=	Digestible energy of the feed (per cent)
UE_T	=	Urinary energy (fraction of GE_T)
ASH_T	=	Ash content of manure (fraction of the dry matter feed intake)
ED_T	=	Energy density of the feed fed to cattle type *T* (MJ/kg-dm)

In the case of sequential treatment stages, the reduction of the volatile solids during a treatment stage is estimated based on site-specific data for different treatment types. Emissions from the next treatment stage are then calculated following the approach outlined above, but with volatile solids adjusted for the reduction from the previous treatment stages by multiplying by (1 - *RVS*), where *RVS* is the relative reduction of volatile solids from the previous stage. The relative reduction of volatile solids (*RVS*) depends on the treatment technology and should be estimated in a conservative manner.

5.2.3 Baseline Methane Conversion Factor

Methane Conversion Factors (*MCF*) values are determined for a specific manure management system and represent the degree to which B_0 is achieved, see Table 5.3 below. The site annual average temperature is taken from official data at the nearest meteorological station, or from data available from historical on site observations;

Table 5.3 *Methane Conversion Factor (MCF) for Non-Anaerobic Storage / Treatment Systems. System definitions are in Table 5.5 of the AMMP protocol, see Appendix A.*

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 5.3** 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%
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%

5.2.4 Baseline GHG Emissions from Fuel & Electric

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.

$$GHG_{elec,B}^{T} = Elec_{B}^{T} \times EF_{elec} \times \frac{1}{2.2046} \quad \text{(Equation 5.7)}$$

Where:

$GHG_{elec,B}^{T}$	=	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)
$Elec_{B}^{T}$	=	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[3] (MWh)
EF_{elec}	=	Emissions factor for electricity in the state in which the dairy is located (lbs CO_2/MWh)[4]
2.2046	=	Conversion factor from lbs to kg

And:

$$GHG_{fuel,B}^{T} = \sum_{f}\left(Fuel_{f,B}^{T} \times EF_{fuel,f}\right) \quad \text{(Equation 5.8)}$$

Where:

$GHG_{fuel,B}^{T}$	=	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)
$Fuel_{f,B}^{T}$	=	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[5] (mmBtu or gallon)
$EF_{fuel,f}$	=	Fuel-specific emission factor (Table 5.4, kg/mmBtu or kg/gal)

[3] 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.
[4] State-specific emissions factors are available via U.S. Energy Information Administration (2023). US Electricity Profile 2022. https://www.eia.gov/electricity/state/
[5] 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.

***Table 5.4** Fuel-specific emissions factors*[6]

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

5.3 Project GHG Emissions

Project activity emissions consist of:

a. Physical leakage of biogas in the manure management systems which includes production, collection and transport of biogas to the point of flaring/combustion or gainful use ($GHG_{PL,p}$)
b. Emissions from flaring or combustion of the gas stream ($GHG_{flare,p}$)
c. Fuel and electricity usage attributable to the manure management project activities.
d. CO_2 emissions from incremental transportation distances
e. Emissions from the storage of manure before being fed into the anaerobic digester ($GHG_{storage,p}$)

$$GHG_P = GHG_{PL,P} + GHG_{flare,P} + GHG_{power,P} + GHG_{transp,P} + GHG_{storage,P} \quad \text{(Equation 5.9)}$$

Where:

GHG_P	=	Project emissions in reporting period *i* (t CO_2e)
$GHG_{PL,P}$	=	Emissions due to physical leakage of biogas in the project reporting period *P* (t CO_2e)
$GHG_{flare,P}$	=	Emissions from flaring or combustion of the biogas stream in the project reporting period *P* (t CO_2e)
$GHG_{power,P}$	=	Emissions from the use of fossil fuel or electricity for the operation of the installed facilities in the project reporting period *P* (t CO_2e)
$GHG_{transp,P}$	=	Emissions from incremental transportation in the project reporting period *P* (t CO_2e)
$GHG_{storage,P}$	=	Emissions from the storage of manure (t CO_2e)

[6] 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).

5.3.1 Project GHG Emissions from Physical Leakage

Project emissions due to physical leakage of biogas from the animal manure management systems used to produce, collect and transport the biogas to the point of flaring or gainful use are estimated as 10% of the maximum methane producing potential of the manure fed into the management systems implemented by the project activity[7]:

$$GHG_{PL,P} = 0.10 \times GWP_{CH4} \times \rho_{CH4} \times \sum_{S,T} \left(B_0^T \times C_i^T \times VS_i^T \times PS_{S,P,i}^T \times nd_i \right) \quad \text{(Equation 5.10)}$$

Where:

$GHG_{PL,P}$	=	Emissions due to physical leakage of biogas in the project reporting period *p* (t CO_2e)
0.10	=	Maximum methane producing potential of the manure fed into the management system due to physical leakage of biogas from the animal manure management systems
GWP_{CH4}	=	Global warming potential of methane (kgCO_2e kgCH_4^{-1})
ρ_{CH4}	=	CH_4 density (0.00067 t/m3 at room temperature (20°C) and 1 atm pressure)
T	=	Index for all types of cattle
S	=	Index for animal manure management system
B_0^T	=	Maximum methane producing potential of the volatile solid generated for cattle type *T* (m^3 CH_4/kg-dm)
C_i^T	=	Average number of animals of type *T* in reporting period *i* (numbers)
VS_i^T	=	Volatile solids production/excretion per head of cattle type *T* in reporting period *i* (on a dry matter weight basis, kg-dm/animal/day) Using Equation 5.6
$PS_{S,P,i}^T$	=	Fraction of manure handled in system *S* in reporting period *i* If the project activity involves sequential manure management systems, the procedure specified in section 5.1.1 above shall be used to estimate the project emissions due to physical leakage of biogas in each stage
nd_i	=	Number of days treatment plant was operational in reporting period *i*

5.3.2 Project GHG Emissions from Flaring

In the case of flaring of the recovered biogas, project emissions are estimated using the procedures described below, as adapted from the methodological tool *Project emissions from flaring*.

If the recovered biogas is combusted for electrical/thermal energy production or for other gainful use, the methane destruction efficiency can be considered as 100%. However, this use of the recovered biogas shall be included in the project boundary and its output shall be

[7] 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Chapter 10 guidelines specify a default value of 10% of the maximum methane producing potential (Bo) for the physical leakages from anaerobic digesters.

monitored in order to ensure that the recovered biogas is actually destroyed, even if the emission reductions from this component are not claimed.

Project emissions from flaring the residual gas ($GHG_{flare,P}$) are based on the flare efficiency ($\eta_{flare,m}$) and the mass flow of methane to the flare ($F_{CH4,RG,m}$). The flare efficiency is determined for each minute m of reporting period *i* based either on monitored data or default values.

The project emissions calculation procedure is given in the following steps:

- STEP 1: Determination of the methane mass flow of the residual gas;
- STEP 2: Determination of the flare efficiency;
- STEP 3: Calculation of project emissions from flaring.

5.3.2.1 Determination of the Methane Mass Flow of the Residual Gas

Tool08, available via the CDM website https://cdm.unfccc.int/Reference/tools/index.html , shall be used to determine the following parameter:

$F_{CH4,m}$	=	Mass flow of methane in the residual gaseous stream in the minute *m* (kg)

The following requirements apply:

a) Tool08 shall be applied to the residual gas;

b) The flow of the gaseous stream shall be measured continuously;

c) CH_4 is the greenhouse gas for which the mass flow should be determined;

d) The simplification offered for calculating the molecular mass of the gaseous stream is valid (equations 3 and 17 in the Tool08); and

e) The time interval for which mass flow should be averaged is every minute *m*.

$F_{CH4,m}$, which is measured as the mass flow during minute *m*, shall then be used to determine the mass of methane in kilograms fed to the flare in the minute *m* ($F_{CH4,RG,m}$). $F_{CH4,m}$ shall be determined on a dry basis.

5.3.2.2 Determination of Flare Efficiency

The flare efficiency depends on the combustion efficiency of the flare and the time that the = flare is operating. To determine the efficiency of enclosed flares project participants shall choose to determine the efficiency based on monitored data or the option to apply a default value. For open flares a default value must be applied. The time the flare is operating is determined by using a flame detector and, in the case of enclosed flares, in addition the monitoring requirements provided by the manufacturer’s operating specifications for operating conditions shall be met.

In the case of open flares, the flare efficiency in the minute m ($\eta_{flare,m}$) is 50% when the flame is detected in the minute m ($Flame_m$), otherwise $\eta_{flare,m}$ is 0%.

In the case of enclosed flares, project participants shall apply a default value for flare efficiency for minute m ($\eta_{flare,m}$).

The flare efficiency for the minute m ($\eta_{flare,m}$)is 90% when the following two conditions are met to demonstrate that the flare is operating, otherwise ($\eta_{flare,m}$) is 0%:

(a) The temperature of the flare ($T_{EG.m}$) and the flow rate of the residual gas to the flare ($F_{RG,m}$) is within the manufacturer's operating specification for the flare ($SPEC_{flare}$) in the minute m; and

(b) The flame is detected in the minute m ($Flame_m$).

For enclosed flares that are defined as low height flares, the flare efficiency shall be adjusted, as a conservative approach, by subtracting 10 percentile points. For example, the default value applied shall be 80%, rather than 90%.

The mass flow of methane in the exhaust gas is determined based on the volumetric flow of the exhaust gas and the measured concentration of methane in the exhaust gas, as follows:

$$F_{CH4,EG,m} = V_{EG,m} \times fc_{CH4,EG,m} \times 10^{-6}$$ (Equation 5.11)

Where:

$F_{CH4,EG,m}$	=	Mass flow of methane in the exhaust gas of the flare on a dry basis at reference conditions in the minute *m* (kg)
$V_{EG,m}$	=	Volumetric flow of the exhaust gas of the flare on a dry basis at reference conditions in the minute *m* (m^3)
$fc_{CH4,EG,m}$	=	Concentration of methane in the exhaust gas of the flare on a dry basis at reference conditions in the minute *m* (mg/m^3)

Determine the average volume flow of the exhaust gas in the minute *m* based on a stoichiometric calculation of the combustion process. This depends on the chemical composition of the residual gas, the amount of air supplied to combust it and the composition of the exhaust gas. It is calculated as follows:

$$V_{EG,m} = Q_{EG,m} \times M_{RG,m}$$ (Equation 5.12)

Where:

$V_{EG,m}$	=	Volumetric flow of the exhaust gas of the flare on a dry basis at reference conditions in the minute *m* (m^3)
$Q_{EG,m}$	=	Volume of the exhaust gas on a dry basis at reference conditions per kilogram of residual gas on a dry basis at reference conditions in the minute m (m3 exhaust gas/kg residual gas)
$M_{RG,m}$	=	Mass flow of the residual gas on a dry basis at reference conditions in the minute m (kg)

Project participants may select to monitor the mass flow of the residual gas in the minute m directly (see monitored parameter $M_{RG,m}$) or, according to the procedure given in this step, calculate $M_{RG,m}$ based on the volumetric flow and the density of the residual gas. The density of the residual gas is determined based on the volumetric fraction of all components in the gas.

$$M_{RG,m} = \rho_{RG,ref,m} \times V_{RG,m} \qquad \text{(Equation 5.13)}$$

Where:

$M_{RG,m}$	=	Mass flow of the residual gas on a dry basis at reference conditions in the minute *m* (kg)
$\rho_{RG,ref,m}$	=	Density of the residual gas at reference conditions in the minute *m* (kg/m^3)
$V_{RG,m}$	=	Volumetric flow of the residual gas on a dry basis at reference conditions in the minute *m* (m^3)

And:

$$\rho_{RG,ref,m} = \frac{P_{ref}}{\frac{R_u}{MM_{RG,m}} \times T_{ref}} \qquad \text{(Equation 5.14)}$$

Where:

$\rho_{RG,ref,m}$	=	Density of the residual gas at reference conditions in the minute *m* (kg/m^3)
P_{ref}	=	Atmospheric pressure at reference conditions (101,325 Pa)
R_u	=	Universal ideal gas constant (0.008314472 Pa.m^3/kmol.K)
$MM_{RG,m}$	=	Molecular mass of the residual gas in the minute *m* (kg/kmol)
T_{ref}	=	Temperature at reference conditions (273.15 K)

Use the equation below to calculate $MM_{RG,m}$. When applying this equation, project participants may choose to either a) use the measured volumetric fraction of each component *c* of the residual gas, or b) as a simplification, measure the volumetric fraction of methane and consider the difference to 100% as being nitrogen (N_2). The same equation applies, irrespective of which option is selected.

$$MM_{RG,m} = \sum_{c} \left(v_{c,RG,m} \times MM_c \right) \qquad \text{(Equation 5.15)}$$

Where:

$MM_{RG,m}$	=	Molecular mass of the residual gas in the minute *m* (kg/kmol)
$v_{c,RG,m}$	=	Molecular mass of residual gas component *c* (kg/kmol)
MM_c	=	Volumetric fraction of component *c* in the residual gas on a dry basis at reference conditions in the hour *h*
c	=	Components of the residual gas. If Option (a) is selected to measure the volumetric fraction, then *c* = CH_4, CO, CO_2, O_2, H_2, H_2S, NH_3, N_2 or if Option (b) is selected then *c* = CH_4 and N_2

The volume of the exhaust gas on a dry basis at reference conditions per kilogram of residual gas ($Q_{EG,m}$) shall be determined as follows:

$$Q_{EG,m} = Q_{CO2,EG,m} + Q_{O2,EG,m} + Q_{N2,EG,m}$$ (Equation 5.16)

Where:

$Q_{EG,m}$	=	Volume of the exhaust gas on a dry basis per kg of residual gas on a dry basis at reference conditions in the minute *m* (m³/kg residual gas)
$Q_{CO2,EG,m}$	=	CO_2 volume in the exhaust gas per kg of residual gas on a dry basis at reference conditions in the minute *m* (m³/kg residual gas)
$Q_{O2,EG,m}$	=	O_2 volume in the exhaust gas per kg of residual gas on a dry basis at reference conditions in the minute *m* (m³/kg residual gas)
$Q_{N2,EG,m}$	=	N_2 volume in the exhaust gas per kg of residual gas on a dry basis at reference conditions in the minute *m* (m³/kg residual gas)

With:

$$Q_{O2,EG,m} = n_{O2,EG,m} \times VM_{ref}$$ (Equation 5.17)

Where:

$Q_{O2,EG,m}$	=	O_2 volume in the exhaust gas per kg of residual gas on a dry basis at reference conditions in the minute *m* (m³/kg residual gas)
$n_{O2,EG,m}$	=	O_2 (moles) in the exhaust gas per kg of residual gas flared on a dry basis at reference conditions in the minute *m* (kmol/kg residual gas)
VM_{ref}	=	Volume of one mole of any ideal gas at reference temperature and pressure (22.4 m³/kmol)

$$Q_{N2,EG,m} = VM_{ref} \times \left\{ \frac{MF_{N,RG,m}}{2 \times AM_N} + \left(\frac{1 - v_{O2,air}}{v_{O2,air}} \right) \times \left[F_{O2,RG,m} + n_{O2,EG,m} \right] \right\}$$ (Equation 5.18)

Where:

$Q_{N2,EG,m}$	=	N_2 volume in the exhaust gas per kg of residual gas on a dry basis at reference conditions in the minute *m* (m³/kg residual gas)
VM_{ref}	=	Volume of one mole of any ideal gas at reference temperature and pressure (22.4 m³/kmol)
$MF_{N,RG,m}$	=	Mass fraction of nitrogen in the residual gas in the minute *m*
AM_N	=	Atomic mass of nitrogen (14.01 kg/kmol)
$v_{O2,air}$	=	Volumetric fraction of O_2 in air (0.21)
$F_{O2,RG,m}$	=	Stochiometric quantity of moles of O_2 required for a complete oxidation of one kg residual gas in the minute *m* (kmol/kg residual gas)

$n_{O2,EG,m}$	=	O_2 (moles) in the exhaust gas per kg of residual gas flared on a dry basis at reference conditions in the minute *m* (kmol/kg residual gas)

$$Q_{CO2,EG,m} = \frac{MF_{C,RG,m}}{AM_C} \times VM_{ref}$$ *(Equation 5.19)*

Where:

$Q_{CO2,EG,m}$	=	CO_2 volume in the exhaust gas per kg of residual gas on a dry basis at reference conditions in the minute *m* (m^3/kg residual gas)
$MF_{C,RG,m}$	=	Mass fraction of carbon in the residual gas in the minute *m*
AM_C	=	Atomic mass of carbon (12.00 kg/kmol)
VM_{ref}	=	Volume of one mole of any ideal gas at reference temperature and pressure (22.4 m^3/kmol)

$$n_{O2,EG,m} = \frac{v_{O2,EG,m}}{1 - \left(\frac{v_{O2,EG,m}}{v_{O2,air}}\right)} \times \left[\frac{MF_{C,RG,m}}{AM_C} + \frac{MF_{N,RG,m}}{2 \times AM_N} + \frac{1 - v_{O2,air}}{v_{O2,air}} \times F_{O2,RG,m}\right]$$ *(Equation 5.20)*

Where:

$n_{O2,EG,m}$	=	O_2 (moles) in the exhaust gas per kg of residual gas flared on a dry basis at reference conditions in the minute *m* (kmol/kg residual gas)
$v_{O2,EG,m}$	=	Volumetric fraction of O_2 in the exhaust gas on a dry basis at reference conditions in the minute *m*
$v_{O2,air}$	=	Volumetric fraction of O_2 in air (0.21)
$MF_{C,RG,m}$	=	Mass fraction of carbon in the residual gas in the minute *m*
AM_C	=	Atomic mass of carbon (12.00 kg/kmol)
$MF_{N,RG,m}$	=	Mass fraction of nitrogen in the residual gas in the minute *m*
AM_N	=	Atomic mass of nitrogen (14.01 kg/kmol)
$F_{O2,RG,m}$	=	Stochiometric quantity of moles of O_2 required for a complete oxidation of one kg residual gas in the minute *m* (kmol/kg residual gas)

$$F_{O2,RG,m} = \frac{MF_{C,RG,m}}{AM_C} + \frac{MF_{H,RG,m}}{4AM_H} - \frac{MF_{O,RG,m}}{2AM_O}$$ *(Equation 5.21)*

Where:

$F_{O2,RG,m}$	=	Stochiometric quantity of moles of O_2 required for a complete oxidation of one kg residual gas in the minute *m* (kmol/kg residual gas)

$MF_{C,RG,m}$	=	Mass fraction of carbon in the residual gas in the minute *m*
AM_C	=	Atomic mass of carbon (12.00 kg/kmol)
$MF_{H,RG,m}$	=	Mass fraction of hydrogen in the residual gas in the minute *m*
AM_H	=	Atomic mass of hydrogen (1.01 kg/kmol)
$MF_{O,RG,m}$	=	Mass fraction of oxygen in the residual gas in the minute *m*
AM_O	=	Atomic mass of oxygen (16.00 kg/kmol)

Determine the mass fractions of carbon, hydrogen, oxygen and nitrogen in the residual gas, using the volumetric fraction of component *c* in the residual gas and applying the equation below. In applying this equation, the project participants may choose to either a) use the measured volumetric fraction of each component *c* of the residual gas, or (b) as a simplification, measure the volumetric fraction of methane and consider the difference to 100% as being nitrogen (N_2). The same equation applies, irrespective of which option is selected.

$$MF_{j,RG,m} = \frac{\sum_c v_{c,RG,m} \times AM_j \times NA_{j,c}}{MM_{RG,m}} \quad \text{(Equation 5.22)}$$

Where:

$MF_{j,RG,m}$	=	Mass fraction of element j in the residual gas in the minute *m*
$v_{c,RG,m}$	=	Volumetric fraction of component *c* in the residual gas on a dry basis in the minute *m*
AM_j	=	Atomic mass of element j (kg/kmol)
$NA_{j,c}$	=	Number of atoms of element j in component *c*
$MM_{RG,m}$	=	Molecular mass of the residual gas in the minute m (kg/kmol)
j	=	Elements C, O, H and N
c	=	Component of residual gas. If Option (a) is selected to measure the volumetric fraction, then *c* = CH_4, CO, CO_2, O_2, H_2, H_2S, NH_3, N_2 or if Option (b) is selected then *c*= CH_4 and N_2

5.3.2.3 Calculation of Project Emissions from Flaring

Project emissions from flaring are calculated as the sum of emissions for each minute *m* in reporting period *i*, based on the methane mass flow in the residual gas ($F_{CH4,RG,m}$) and the flare efficiency ($\eta_{flare,m}$) as follows:

$$GHG_{flare,P} = GWP_{CH4} \times \sum_{m=1}^{525600} F_{CH4,RG,m} \times \left(1 - \eta_{flare,m}\right) \times 10^{-3} \quad \text{(Equation 5.23)}$$

Where:

$GHG_{flare,P}$	=	Emissions from flaring or combustion of the biogas stream in the project reporting period *P* (t CO_2e)
GWP_{CH4}	=	Global warming potential of methane (kgCO_2e kgCH_4^{-1})
$F_{CH4,RG,m}$	=	Mass flow of methane in the residual gas in the minute *m* (kg)
$\eta_{flare,m}$	=	Flare efficiency in the minute *m*

5.3.3 Project GHG Emissions from Transportation

Project emissions due to incremental transport distances ($GHG_{transp,P}$) are calculated based on the incremental distances between:

(a) The collection points of biomass and/or manure and the digestion site as compared to the baseline solid waste disposal site or manure treatment site;

(b) When applicable, the collection points of wastewater and treatment site as compared to baseline wastewater treatment site;

(c) Treatment sites and the sites for soil application, landfilling and further treatment of the residual waste.

$$GHG_{transp,P} = \left(\frac{Q_i}{CT_i}\right) \times DAF_w \times EF_{CO2,transp} + \left(\frac{Q_{reswaste,i}}{CT_{reswatste,i}}\right) \times DAF_{reswaste} \times EF_{CO2,transp} \quad \text{(Equation 5.24)}$$

Where:

$GHG_{transp,P}$	=	Emissions from incremental transportation in the project reporting period *P* (t CO_2e)
Q_i	=	Quantity of raw waste/manure treated and/or wastewater co-digested in the reporting period *i* (tonnes)
CT_i	=	Average truck capacity for transportation (tonnes/truck)
DAF_w	=	Average incremental distance for raw solid waste/manure and/or wastewater transportation (km/truck)
$EF_{CO2,transp}$	=	CO_2 emission factor from fuel use due to transportation (kgCO_2/km, IPCC default values or local values may be used)
$Q_{reswaste,i}$	=	Quantity of residual waste produced in the reporting period *i* (tonnes)
$CT_{reswatste,i}$	=	Average truck capacity for residual waste transportation (tonnes/truck)
$DAF_{reswaste}$	=	Average distance for residual waste transportation (km/truck)

5.3.4 Project GHG Emissions from Fuel & Electric

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 5.12. In the absence of manure management-specific data, total electricity consumption for the dairy may be used.

Project 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.

$$GHG_{power,P} = \sum_T \left(GHG^T_{elec,P} + GHG^T_{fuel,P}\right) \quad \text{(Equation 5.25)}$$

Where:

$GHG_{power,P}$	=	Emissions from the use of fossil fuel or electricity for the operation of the installed facilities in the project reporting period P (t CO2e)
$GHG^T_{elec,P}$	=	GHG emissions from electricity use for manure management activities for cattle type T during the reporting period (kg CO2)
$GHG^T_{fuel,P}$	=	GHG emissions from fuel use for manure management activities for cattle type T during the reporting period (kg CO2eq)

Using:

$$GHG^T_{elec,P} = Elec^T_P \times EF_{elec} \times \frac{1}{2.2046} \quad \text{(Equation 5.26)}$$

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)[8]
2.2046	=	Conversion factor from lbs to kg

And:

$$GHG^T_{fuel,P} = \sum_f \left(Fuel^T_{f,P} \times EF_{fuel,f}\right) \quad \text{(Equation 5.27)}$$

Where:

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

$GHG^{T}_{fuel,P}$	=	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 5.4**) (kg/MMBtu or kg/gal)

5.3.5 Project GHG Emissions from Manure Storage

Project emissions on account of storage of manure before being fed into the anaerobic digester shall be accounted for if both condition (a) and condition (b) below are satisfied:

a. The storage time of the manure after removal from the animal barns, including transportation, exceeds 24 hours before being fed into the anaerobic digester

b. The dry matter content of the manure when removed from the animal barns is less than 20%

The following method shall be used to calculate project emissions from manure storage:

$$GHG_{storage,P} = GWP_{CH4} \times \rho_{CH4} \times \sum_{T,S}\left[\frac{365}{AI_S} \times \sum_{d=1}^{AI}\left(C_i^T \times VS_d^T \times PS_{S,P,i}^T \times \left(1 - e^{-k(AI_S - d)}\right) \times MCF_S \times B_0^T\right)\right] \quad \text{(Equation 5.28)}$$

Where:

$GHG_{storage,P}$	=	Project emissions on account of manure storage in project reporting period *p* (t CO2e)
GWP_{CH4}	=	Global warming potential of methane ($kgCO_2e\ kgCH_4^{-1}$)
ρ_{CH4}	=	CH_4 density (0.00067 t/m3 at room temperature (20°C) and 1 atm pressure)
T	=	Index for all types of cattle
S	=	Index for animal manure management system
AI_S	=	Average interval between manure collection and delivery for treatment at a given storage device *S* (days)
C_i^T	=	Average number of animals of type *T* in reporting period *i* (numbers)
VS_i^T	=	Volatile solids production/excretion per head of cattle type *T* in reporting period *i* (on a dry matter weight basis, kg-dm/animal/day). Using Equation 5.6
$PS_{S,P,i}^T$	=	Percentage of volatile solids handled by storage device *S* from cattle type *T* in the project reporting period *P*
k	=	Degradation rate constant (0.069)
d	=	Days for which cumulative methane emissions are calculated; d can vary from 1 to 45 and to be run from 1 up to AI_S
MCF_S	=	Methane conversion factor for the project manure storage device *S* from Table 5.3
B_0^T	=	Maximum methane producing potential of the volatile solid generated for cattle type *T* ($m^3\ CH_4$/kg-dm)

5.4 Leakage & Permanence

It is determined by following the relevant procedure in the methodology above.

5.5 Uncertainty

Uncertainty is accounted for by UD_B in Equation 5.4.

5.6 Deviations from Protocol Methodologies

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

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.

The monitoring plan should include on-site inspections for each individual farm included in the project boundary where the project activity is implemented on a basis consistent with the regular review of this protocol, at minimum annually. If it becomes necessary due to growing size of the program of activities, a risk-based sampling method may be adopted in the future. If so, the sampling method shall be separately vetted for rigor and accuracy.

If a project replaces equipment, the initial engineering audit must confirm that the new equipment is as good as or better than the equipment that is replaced or that the project has correctly calculated the new emissions.

If the project activity involves the replacement of equipment, and the leakage effect of the use of the replaced equipment in another activity is neglected, because the replaced equipment is scrapped, an independent monitoring of scrapping of replaced equipment needs to be implemented. The monitoring should include a check if the number of project activity equipment distributed by the project and the number of scrapped equipment correspond with each other. For this purpose, scrapped equipment should be stored until such correspondence has been checked. The scrapping of replaced equipment should be documented and independently verified. or the leakage has been correctly accounted for.

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 practice of replacing or modifying anaerobic animal manure management systems in livestock farms to achieve methane recovery and destruction by flaring/combustion or gainful use of the recovered methane.

This includes:

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. The monitoring report must include an attestation as to regulatory compliance.
11. The monitoring report should be submitted no less frequently than annually and no more frequently than 30 days.
12. The monitoring period can be as short as 30 days. The maximum monitoring period is 12 months.
13. The monitoring report must be submitted and shared with Athian, as the program administrator.

6.1 Data Quality Assurance

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*

Parameter	Description	Data Unit	Values Applied	Data Source	Measurement Frequency	Measurement Procedure
$BG_{burnt,i}$	Biogas flared or combusted in reporting period *i*	m^3				
$w_{CH4,i}$	Methane content in biogas in the reporting period *i*	Volume fraction				
FE	Flare efficiency in the reporting period *i*	Fraction				
GWP_{CH4}	Global warming potential of methane	$kgCO_2e\ kgCH_4^{-1}$	29.8	Reference	N/A	
EG_i	Total electricity generated from the recovered biogas in reporting period *i*	MWh				
EE_i	Energy conversion efficiency of the project equipment	Percent	As specified or default 40%	Operating records or reference	Once per change in equipment or N/A	Compare with specification provided by the equipment manufacture or use the default efficiency value.
T	Types of cattle included in the project	Cattle Type	Type of cattle	Operating records	Each reporting period	Compared to herd management records or reports obtained from the producer
S	Types of animal manure management systems	System Type	Type of system	Operating records	Each reporting period	Compared to on-farm management records or reports obtained from the producer
MCF_S	Methane conversion factor (*MCF*) for the animal manure management system *S*	Percent	Table 5.3	Reference	Once per change in equipment	
B_0^T	Maximum methane producing potential of the volatile solid generated for cattle type *T*	$m^3\ CH_4$/kg-dm	Table 5.2	Reference	Each reporting period	
C_i^T	Average number of animals of type *T* in reporting period *i*	Head	Number of cattle	Operating records	Each reporting period	Compared to herd management records or reports obtained from the producer

VS_i^T	Volatile solids production/excretion per head of cattle type *T* in reporting period *i*	kg-dm/animal/day	Approx. 5.4 to 7.7	Calculated	Each reporting period	
$PS_{S,B}^T$	Fraction of manure handled in baseline animal manure management system *S* by cattle type *T*	Percent	0 to 100%	Operating records	Each reporting period	Compared to on-farm management records or reports obtained from the producer
GE_T	Daily average gross energy intake of cattle type *T*	MJ/head/day		Calculated using operating records	Each reporting period	Compare calculated value to expected range (i.e. min and max acceptable values) using standardized NASEM feed library values and on-farm reporting of feed composition
DE_T	Digestible energy of the feed fed to cattle type *T*	Fraction of GE_T		Calculated using operating records	Each reporting period	Compare calculated value to expected range (i.e. min and max acceptable values) using standardized NASEM feed library values and on-farm reporting of feed composition
UE_T	Urinary energy of the feed fed to cattle type T	Fraction of GE_T		Calculated using operating records	Each reporting period	Compare calculated value to expected range (i.e. min and max acceptable values) using standardized NASEM feed library values and on-farm reporting of feed composition
ASH_T	Ash content of the feed fed to cattle type T	Fraction of DMI		Calculated using operating records	Each reporting period	Compare calculated value to expected range (i.e. min and max acceptable values) using standardized NASEM feed library values and on-farm reporting of feed composition
ED_T	Energy density of the feed fed to cattle type *T*	MJ/kg-dm		Calculated using operating records	Each reporting period	
nd_i	Number of days treatment plant was operational in reporting period *i*	Days	Number of days			

$F_{CH4,m}$	Mass flow of methane in the residual gaseous stream in the minute *m*	kg		Calculated	Each reporting period	
$F_{CH4,EG,m}$	Mass flow of methane in the exhaust gas of the flare on a dry basis at reference conditions in the minute *m*	kg		Calculated	Each reporting period	
$V_{EG,m}$	Volumetric flow of the exhaust gas of the flare on a dry basis at reference conditions in the minute *m*	m^3		Calculated	Each reporting period	
$fc_{CH4,EG,m}$	Concentration of methane in the exhaust gas of the flare on a dry basis at reference conditions in the minute *m*	mg/m^3		Calculated	Each reporting period	
$Q_{EG,m}$	Volume of the exhaust gas on a dry basis at reference conditions per kilogram of residual gas on a dry basis at reference conditions in the minute m	m3 exhaust gas/kg residual gas		Calculated	Each reporting period	
$M_{RG,m}$	Mass flow of the residual gas on a dry basis at reference conditions in the minute m	kg		Calculated	Each reporting period	
$\rho_{RG,ref,m}$	Density of the residual gas at reference conditions in the minute *m*	kg/m^3		Calculated	Each reporting period	
$V_{RG,m}$	Volumetric flow of the residual gas on a dry basis at reference conditions in the minute m	m^3		Calculated	Each reporting period	
$MM_{RG,m}$	Molecular mass of the residual gas in the minute *m*	kg/kmol		Calculated	Each reporting period	
$v_{c,RG,m}$	Molecular mass of residual gas component *c*	kg/kmol		Calculated	Each reporting period	
MM_c	Volumetric fraction of component c in the residual gas on a dry basis at reference conditions in the hour			Calculated	Each reporting period	

$Q_{EG,m}$	Volume of the exhaust gas on a dry basis per kg of residual gas on a dry basis at reference conditions in the minute *m*	m^3/kg residual gas		Calculated	Each reporting period	
$Q_{CO2,EG,m}$	CO_2 volume in the exhaust gas per kg of residual gas on a dry basis at reference conditions in the minute *m* (m^3/kg residual gas)	m^3/kg residual gas		Calculated	Each reporting period	
$Q_{O2,EG,m}$	O_2 volume in the exhaust gas per kg of residual gas on a dry basis at reference conditions in the minute *m* (m^3/kg residual gas)	m^3/kg residual gas		Calculated	Each reporting period	
$Q_{N2,EG,m}$	N_2 volume in the exhaust gas per kg of residual gas on a dry basis at reference conditions in the minute *m* (m^3/kg residual gas)	m^3/kg residual gas		Calculated	Each reporting period	
$n_{O2,EG,m}$	O_2 (moles) in the exhaust gas per kg of residual gas flared on a dry basis at reference conditions in the minute *m*	kmol/kg residual gas		Calculated	Each reporting period	
$MF_{N,RG,m}$	Mass fraction of nitrogen in the residual gas in the minute *m*			Calculated	Each reporting period	
$F_{O2,RG,m}$	Stochiometric quantity of moles of O_2 required for a complete oxidation of one kg residual gas in the minute *m*	kmol/kg residual gas		Calculated	Each reporting period	
$MF_{C,RG,m}$	Mass fraction of carbon in the residual gas in the minute *m*			Calculated	Each reporting period	
$v_{O2,EG,m}$	Volumetric fraction of O_2 in the exhaust gas on a dry basis at reference conditions in the minute *m*			Calculated	Each reporting period	
$MF_{H,RG,m}$	Mass fraction of hydrogen in the residual gas in the minute *m*			Calculated	Each reporting period	

$MF_{O,RG,m}$	Mass fraction of oxygen in the residual gas in the minute *m*			Calculated	Each reporting period	
$MF_{j,RG,m}$	Mass fraction of element j in the residual gas in the minute *m*			Calculated	Each reporting period	
AM_j	Atomic mass of element j	kg/kmol		Calculated	Each reporting period	
$NA_{j,c}$	Number of atoms of element j in component *c*			Calculated	Each reporting period	
$\eta_{flare,m}$	Flare efficiency in the minute *m*			Calculated	Each reporting period	
Q_i	Quantity of raw waste/manure treated and/or wastewater co-digested in the reporting period *i*	tonnes		Calculated	Each reporting period	
CT_i	Average truck capacity for transportation	tonnes/truck		Calculated	Each reporting period	
DAF_w	Average incremental distance for raw solid waste/manure and/or wastewater transportation	km/truck		Calculated	Each reporting period	
$EF_{CO2,transp}$	CO_2 emission factor from fuel use due to transportation	$kgCO_2/km$		Calculated	Each reporting period	IPCC default or local values may be used
$Q_{reswaste,i}$	Quantity of residual waste produced in the reporting period i	tonnes		Calculated	Each reporting period	
$CT_{reswatste,i}$	Average truck capacity for residual waste transportation	tonnes/truck		Calculated	Each reporting period	
$DAF_{reswaste}$	Average distance for residual waste transportation	km/truck		Calculated	Each reporting period	

$Elec_B^T$	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				Compared to on-farm management records or reports obtained from the producer
EF_{elec}	Emissions factor for electricity in the state in which the dairy is located	lbs CO_2/MWh		Reference	Each reporting period	Using U.S. Energy Information Administration (2022). US Electricity Profile 2021. www.eia.gov/electricity/state
$Fuel_{f,B}^T$	The average amount of fuel type f 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 gallons				Compared to on-farm management records or reports obtained from the producer
$EF_{fuel,f}$	Fuel-specific emission factor	kg/mmBtu or kg/gal	Table 5.4	Reference	Each reporting period	N/A
$PS_{S,P,i}^T$	Fraction of manure handled in project animal manure management system *S* by cattle type *T*	Percent	0% - 100%	Operating records	Each reporting period	Compared to on-farm management records or reports obtained from the producer
$Elec_P^T$	Amount of electricity used for manure management activities for cattle type T during the reporting period	MWh				Compared to on-farm management records or reports obtained from the producer
$Fuel_{f,P}^T$	Quantity of fuel of each fuel type f consumed in the reporting period for manure management activities for cattle type T	mmBtu or gallons				Compared to on-farm management records or reports obtained from the producer

AI_S	Average interval between manure collection and delivery for treatment at a given storage device S	Days				
d	Days for which cumulative methane emissions are calculated	Days	1-45			

7 Reporting

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

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

7.1 Record Keeping

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

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

1 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.

1.1 Verification Body Requirements

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

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

1.2 Conflict of Interest

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

1.3 Verification Process

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

1. Complete a COI evaluation. If there is a potential COI, the VVB is not allowed to conduct the verification.
2. Prepare a verification plan that includes, at a minimum:
    a. A list of people from the VVB involved in the verification,
    b. A list of the location and dates of any on-site visits that will be conducted,
    c. The types of data and documents that will be reviewed by the VVB,
    d. A list of the people who are expected to be interviewed as a part of the verification.
3. Conduct a kick-off meeting with all parties to lay out the timeline and process of the verification.
4. Undertake a desk review of the data from the project.

Completion of a verification report stating any issues identified during the verification and their classification as either material (significant) or immaterial (insignificant).

8 References

Project participants shall take into account the "General guidelines for SSC CDM methodologies" and the "Guidelines on the demonstration of additionality of small-scale project activities" (Attachment A to Appendix B) provided at:
http://cdm.unfccc.int/methodologies/SSCmethodologies/approved.html

This methodology also refers to the latest approved versions of the following methodologies and tools:

- *ACM0010: Consolidated baseline methodology for GHG emission reductions from manure management systems;*
- *AM0073: GHG emission reductions through multi-site manure collection and treatment in a central plant;*
- *AMS-III.F: Avoidance of methane emissions through composting;*
- *AMS-III.G: Landfill methane recovery;*
- *AMS-III.H: Methane recovery in wastewater treatment;*
- *AMS-III.AO: Methane recovery through controlled anaerobic digestion;*
- Methodological Tool: *Project and leakage emissions from anaerobic digesters;*
- Methodological Tool: *Project emissions from flaring;*
- *Tool to calculate baseline, project and/or leakage emissions from electricity consumption;*
- *Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion.*

Appendix A. Alternative Manure Management (AMMP)

This protocol is used in conjunction with the latest approved version of Athian's Alternative Manure Management Protocol (PRO-00000003). The most recent version of the protocol can be found at www.athian.ag/methods#protocol-library.