GRAZING LAND AND LIVESTOCK MANAGEMENT GREENHOUSE GAS MITIGATION METHODOLOGY

MODULE NAME:

ACCOUNTING MODULE FOR EMISSIONS FROM MANURE

MODULE CODE:

A-MANURE

Output Parameter(s)
Parameter Name: E_MAN
Parameter Description: Net manure emissions (t CO_2e)

Key Input Data:
- Manure management system
- Feces production
- Volatile solids in feces
- Ambient temperatures
- Manure pH
- Manure stored and manure losses from storage

Purpose
To estimate emissions and net emission reductions from manure as part of grazing land and livestock management greenhouse gas mitigation activities.
The module estimates both emissions in the baseline case and with project implementation.

The following practices are covered under this methodology:
- Animals housed in barns
- Animals housed in open lots
- Unenclosed manure storage with and without crust on top
- Stacked dry manure storage
- Enclosed manure storage with methane capture
- Application of stored manure to fields
- Livestock grazed on fields

Applicability Conditions
The module is applicable to all projects accounted under this methodology.
Where with-project emissions are significantly elevated (see T-XANTE) the module shall be used, in all other cases it is optional.

1.0 Calculation Procedure

Manure emissions are divided between carbon dioxide, methane and nitrous oxide emissions. Each are calculated on a daily basis and subsequently summed for reporting.

The calculation approach is derived from the process model Dairy GEM. Users may elect to use the fully parameterized model directly. Where the fully parameterized model is not used directly, but instead the equations presented here are used without running the model, then calculations must be presented at a minimum monthly with average conditions (e.g. temperature), recorded for the specific month, used for the month being examined.

The baseline shall be dynamic. *Ex ante* all projected emissions and emissions reductions should be estimated. However, results shall be presented at the time of reporting with the specific baseline and project-case emissions estimated based on variables (temperatures, livestock numbers, manure quantities, manure characteristics etc.) recorded in the specific year.

1.1 Carbon Dioxide

Total carbon dioxide emission from manure:

Total carbon dioxide emissions are equal to the emissions from the flaring of methane from enclosed manure storage. CO_2 emissions from the barn floor and from stored manure are ignored, since biogenic.

$$E_{CO2} = \left(E_{CO2,flare}\right)/1000 \quad \textbf{(1)}$$

Where:

E_{CO2}	Daily rate of CO_2 emission from manure; t $CO_2.day^{-1}$
$E_{CO2,flare}$	Emission of CO_2 from combustion of captured CH_4; kg $CO_2.day^{-1}$

Emission from flaring captured CH_4 ($E_{CO2,flare}$):

$$E_{CO2,flare} = E_{CH4,cov} * 2.75 \quad \textbf{(2)}$$

Where:

$E_{CO2,flare}$	Emission of CO_2 from combustion of captured CH_4; kg $CO_2.day^{-1}$
$E_{CH4,cov}$	Daily rate of CH_4 emission from enclosed storage; kg $CH_4.day^{-1}$ (see equation 12)
2.75	Ratio of molecular weights of CO_2 and CH_4; dimensionless

1.2 Methane

Total methane emission from manure:

Total methane emissions are equal to the sum of emissions from the floor of barns and open lots, from stored manure either covered or uncovered or in dry stacks, from manure applied to fields, and manure from grazing animals:

$$E_{CH4} = \left(\sum_{fl} E_{CH4,floor} + \sum_{st} E_{CH4,man} + E_{CH4,cov} + E_{CH4,stack} + E_{CH4,app} + E_{CH4,grz}\right) * \frac{21}{1000} \quad \textbf{(3)}$$

Where:

E_{CH4}	Daily rate of CH_4 emission from manure; t $CO_2e.day^{-1}$
$E_{CH4,floor}$	Daily rate of CH_4 emission from the floor; kg $CH_4.day^{-1}$
$E_{CH4,man}$	Daily rate of CH_4 emission from unenclosed storage; kg CH_4/day
$E_{CH4,cov}$	Daily rate of CH_4 emission from enclosed storage; kg $CH_4.day^{-1}$
$E_{CH4,stack}$	Daily rate of CH_4 emission from stacks; kg $CH_4.day^{-1}$
$E_{CH4,app}$	Daily rate of CH_4 emission from manure application to fields; kg $CH_4.day^{-1}$
$E_{CH4,grz}$	Daily rate of CH_4 emission from manure from grazing animals; kg $CH_4.day^{-1}$
st	1, 2, 3 …. *st* forms of unenclosed manure storage
fl	1, 2, 3 …. *fl* forms of manure management on floor (barns/lots)
21	Global warming potential of methane (SAR-100 value in IPCC AR4 2007)
1000	Conversion from kg to metric tonnes

CH_4 Conversion Factor for Manure Management Systems (*MCF*):

The methane conversion factor is calculated here and used in later equations for estimating emissions. The calculations given here shall be used for MCF except where a literature value exists and can be justified for application in the project site.

Where animals are housed in barns:

$$MCF = 7.11e^{0.0884*T_b} \tag{4}$$

Where:

MCF	CH_4 conversion factor for manure management system
T_b	Ambient temperature in barn; ^oC *

(If MCF >80 use 80, if MCF <0 use 0)

*Where temperature recorded in ^oF, $^oC = ((^oF-32) * 5) / 9$

Where animals are housed in open lots:

$$MCF = 0.0625 * T_a - 0.25 \tag{5}$$

Where:

MCF	CH_4 conversion factor for manure management system
T_a	Ambient temperature in open lot; ^oC *

(If MCF <0 use 0)

*Where temperature recorded in ^oF, $^oC = ((^oF-32) * 5) / 9$

Where free stall and open housing are combined:

Use known proportions of time in each category for calculations.

Where manure is stored in stacks:

$$MCF = 0.201 * T_m - 0.29 \tag{6}$$

Where:

MCF	CH_4 conversion factor for manure management system
T_m	Ambient temperature of manure; ^oC *

(If MCF <0 use 0)

*Where temperature recorded in ^oF, $^oC = ((^oF-32) * 5) / 9$

Emission from the floor ($E_{CH4,floor}$):

For free stall and tie stall barn floors:

$$E_{CH4,floor} = \max(0, 0.13 * T_b) * A_{barn} / 1000 \quad (7)$$

Where:

$E_{CH4,floor}$ Daily rate of CH_4 emission from the floor; kg CH_4.day^{-1}

T_b Ambient temperature in barn; ^oC *

A_{barn} Floor area covered by manure; m^2 #

*Where temperature recorded in ^oF, $^oC = ((^oF-32) * 5) / 9$

#Where barn area recorded in ft^2, $m^2 = ft^2 * 0.0929$

Emission where manure is allowed to accumulate into a bedded pack:

$$E_{CH4,floor} = (VS_T * B_m * 0.67 * MCF)/100 \quad (8)$$

Where:

$E_{CH4,floor}$ Daily rate of CH_4 emission from the floor; kg CH_4.day^{-1}

VS_T Volatile solid contained in the storage on a given day; kg

B_m Maximum CH_4 producing capacity of manure; m^3 CH_4.kg VS^{-1} (default 0.24)

0.67 Conversion factor m^3 CH_4 to kg CH_4

MCF CH_4 conversion factor for manure management system (see equation 4-5)

$$VS_T = M_{manure} * P_{TS} * P_{VS} - VS_{lossT} \quad (9)$$

Where:

VS_T Volatile solid contained in the storage on a given day; kg

M_{manure} Accumulated mass of manure entering storage; kg *

P_{TS} Total solid content of manure; kg TS.kg manure^{-1}

P_{VS} Fraction of *VS* in total solids; kg VS.kg total solid^{-1} (default: heifers 0.726, dry cows 0.698, lactating cows 0.68)

VS_{lossT} Accumulated VS_{loss}; kg (Equal to 3 times methane emission)

* Where mass of manure is in pounds, kg = pounds * 0.4536

Emission from manure storage ($E_{CH4,man}$ / $E_{CH4,cov}$/ $E_{CH4,stack}$):

Where storage is in slurry with crust on surface:

$$E_{CH4,man} = 0.024 * VS_T * (VS_d + VS_{nd} * 0.01) * e^{\ln(A) - E/RT} \quad (10)$$

Where:

$E_{CH4,man}$	Daily rate of CH_4 emission from unenclosed storage; kg CH_4/day
VS_T	Volatile solid contained in the storage on a given day; kg
$VS_d + VS_{nd}$	Degradable and non-degradable *VS* fractions in manure; kg.kg^{-1} VS
A	Arrhenius parameter; g CH_4.kg VS^{-1} (default: ln(A) = 43.33)
E	Apparent activation energy; J.mol^{-1} (default: 112,700)
R	Gas constant; J.k^{-1}.mol^{-1} (default: 8.314)
T_k	Ambient temperature of stored slurry; ^oK *

*Where temperature recorded in ^oF, $^oK = (((^oF-32) * 5) / 9) + 273$

$$VS_d = \frac{VS_{in} * \left(B_0 / E_{CH4,pot}\right) - VS_{loss}}{VS_T} \quad \textbf{(11)}$$

Where:

VS_d	Degradable *VS* fractions in manure; kg.kg^{-1} VS
VS_T	Volatile solid contained in the storage on a given day; kg
VS_{loss}	*VS* lost from storage in a given day; kg *
B_o	Achievable emission of CH_4 during anaerobic digestion; kg CH_4.kg VS^{-1} (default: 0.2)
$E_{CH4,pot}$	Potential CH_4 yield of manure; kg CH_4/day (default: 0.48)

* Where mass of manure is in pounds, kg = pounds * 0.4536

Where storage is top loaded or DM < 7%:
$E_{CH4,man}$ shall be increased by 60%

Where storage is covered (but not sealed):
$E_{CH4,man}$ shall be decreased by 50%

Where storage is enclosed:

$$E_{CH4,cov} = E_{CH4,man} * (1 - n_{eff}) \quad \textbf{(12)}$$

Where:

$E_{CH4,cov}$	Daily rate of CH_4 emission from enclosed storage; kg CH_4.day^{-1}
$E_{CH4,man}$	Daily rate of CH_4 emission from storage; kg CH_4.day^{-1}
n_{eff}	Efficiency of collection; % (Default: 99%)

Where manure is stored semi-solid (8-14% DM) or solid (>15% DM) in stacks:

$$E_{CH4,stack} = VS_T * B_m * 0.67 * MCF / 100 \quad \textbf{(13)}$$

Where:

$E_{CH4,stack}$	Daily rate of CH_4 emission from stacks; kg CH_4.day^{-1}
VS_T	Volatile solid contained in the storage on a given day; kg *
B_m	Maximum CH_4 producing capacity of manure; m^3 CH_4.kg VS^{-1} (default 0.24)
0.67	Conversion factor m^3 CH_4 to kg CH_4
MCF	CH_4 conversion factor for manure management system (see equation 7)

* Where mass of manure is in pounds, kg = pounds * 0.4536

Emission from field application of manure ($E_{CH4,app}$):

$$E_{CH4,app} = (0.170 * F_{VFA} + 0.026) * 0.032 * A_{man} / r_{app} \quad \textbf{(14)}$$

Where:

$E_{CH4,app}$	Daily rate of CH_4 emission from manure application to fields; kg CH_4.day^{-1}
F_{VFA}	Daily concentration of VFAs in slurry; mmol.kg^{-1}
A_{man}	Amount of manure applied on fields; kg *
r_{app}	Application rate on fields; kg.ha^{-1} #

* Where mass of manure is in pounds, kg = pounds * 0.4536
# Where application rate is in pounds per acre, kg per ha = pounds per acre * 0.893

$$F_{VFA} = F_{VFAi} * e^{-0.6939t} \quad \textbf{(15)}$$

Where:

F_{VFA}	Daily concentration of VFAs in slurry; mmol.kg^{-1}
F_{VFAi}	Initial VFA concentration in slurry; mmol.kg^{-1}
t	Time since application with t=0 being day of application

$$F_{VFAi} = [F_{TAN} / 2.02] * (9.43 - pH) \quad \textbf{(16)}$$

Where:

F_{VFAi}	Initial VFA concentration in slurry; mmol.kg^{-1}
F_{TAN}	Concentration of NH_4^+ and NH_3 in slurry; mmol.kg^{-1}

Emission from manure from grazing animals ($E_{CH4,grz}$):

$$E_{CH4,grz} = FEC * EF_{fec} \quad \textbf{(17)}$$

Where:

$E_{CH4,app}$	Daily rate of CH_4 emission from manure from grazing animals; kg CH_4.day^{-1}
FEC	Daily fecal production by grazing animals; kg

EF_{fec}	Emission factor for feces on pasture/grassland/rangeland; kg CH_4.kg feces^{-1} (default: 0.000086)

1.3 Nitrous Oxide

Total nitrous oxide emission from manure:

Total nitrous oxide emissions are equal to the sum of emissions from the floor of barns or dry lots and from the unenclosed storage of manure or stacked dry manure.

$$E_{N2O} = \left(\sum_{fl} E_{N2O,floor} + E_{N2O,man} \right) * 1.57 * \frac{310}{1000} \quad \textbf{(18)}$$

Where:

E_{N2O}	Daily rate of N_2O emission from manure; t CO_2e.day^{-1}
$E_{N2O,floor}$	Daily rate of N_2O emission from the floor; kg CH_4.day^{-1}
$E_{N2O,man}$	Daily rate of N_2O emission from storage; kg CH_4/day
fl	1, 2, 3 …. *fl* forms of manure management on floor (barns/lots)
310	Global warming potential of N_2O (SAR-100 value in IPCC AR4 2007)
1000	Conversion from kg to metric tonnes

Floors of free stand and tie stall barns ($E_{N2O,floor}$):
Zero N_2O emissions

Bedded pack floors ($E_{N2O,floor}$):
$E_{N2O,floor}$ is equal to 0.01 kg N_2O-N per kg N excreted

Dry lot floors ($E_{N2O,floor}$):
$E_{N2O,floor}$ is equal to 0.02 kg N_2O-N per kg N excreted

Emission from manure storage ($E_{N2O,man}$):

Where storage is in slurry with crust on surface:

$$E_{N2O,man} = EF_{N2O,man} * A_{storage} / 1000 \quad \textbf{(19)}$$

Where:

$E_{N2O,man}$	Emission of N_2O from stored manure; kg N_2O.day^{-1}
$EF_{N2O,man}$	Emission rate of N_2O from slurry with crust; g N_2O.m^{-2}.day^{-1} (default: 0.8)
$A_{storage}$	Exposed surface area of manure storage; m^2 *

#Where area recorded in ft^2, m^2 = ft^2 * 0.0929

Where no crust is formed on top of stored manure:

Zero N_2O emissions
Occurs where DM < 8% OR manure loaded daily to top OR an enclosed tank is used.

Where manure is stacked:
$E_{N2O,man}$ is equal to 0.005 kg N_2O-N per kg N excreted

1.4 Summation

Total daily manure emissions are equal to the summed emissions from carbon dioxide, methane and nitrous oxide.

$$E_{manure} = E_{CO2} + E_{CH4} + E_{N2O} \quad \textbf{(20)}$$

Where:

E_{manure}	Daily rate of emission from manure; t $CO_2e.day^{-1}$
E_{CO2}	Daily rate of CO_2 emission from manure; t $CO_2.day^{-1}$
E_{CH4}	Daily rate of CH_4 emission from manure; t $CO_2e.day^{-1}$
E_{N2O}	Daily rate of N_2O emission from manure; t $CO_2e.day^{-1}$

Summed baseline emissions or project emissions up to any point in time are the sum of the daily emissions. Where livestock management and manure management changes through the year (for example when cows are on pasture in summer months and in the barn during the winter) then the number of days for each of the practices should be summed.

$$E\_MAN_{BSL/P} = \sum_t E_{manure} \quad \textbf{(21)}$$

Where:

E_MAN_{BSL}	Manure emissions in the baseline; t CO_2e
E_MAN_P	Manure emissions in the project scenario; t CO_2e
E_{manure}	Daily rate of emission from manure; t $CO_2e.day^{-1}$

Net emissions are equal to baseline emissions minus project emissions.

$$E\_MAN_{prelim} = E\_MAN_{BSL} - E\_MAN_P \quad \textbf{(22)}$$

Where:

E_MAN	Net manure emissions prior to uncertainty deductions; t CO_2e
E_MAN_{BSL}	Manure emissions in the baseline; t CO_2e
E_MAN_P	Manure emissions in the project scenario; t CO_2e

1.4.1 Uncertainty

Uncertainty shall be quantified by means of a Monte Carlo statistical analysis. The analysis shall combine uncertainties across each of the categories, and between baseline and project scenarios.

The output (E_MAN_{ERROR}) shall be the half width of the ultimate calculated 90% confidence interval divided by estimated net manure emissions.

If $E\_MAN_{ERROR} \leq 10\%$ of E_MAN_{prelim} then no deduction for uncertainty is required ($E\_MAN_{prelim} = E\_MAN$).

If $E\_MAN_{ERROR} > 10\%$ of E_MAN_{prelim} then the modified value for EE to account for uncertainty shall be:

$$E\_MAN = E\_MAN_{prelim} - \left(E\_MAN_{prelim} * \left(E\_MAN_{ERROR} - 10\%\right)\right) \quad \textbf{(23)}$$

Where:

E_MAN	Net enteric emissions; t CO_2-e
E_MAN_{prelim}	Net enteric emissions prior to uncertainty deductions; t CO_2-e
E_MAN_{ERROR}	Total uncertainty for enteric emissions; %

2.0 Input Data Sources and Requirements

2.1 Data for validation

Parameter	$\mathbf{B_m}$
Units	$\mathbf{m^3\ CH_4.kg\ VS^{-1}}$
Description	Maximum CH_4 producing capacity of manure
Relevant Section	**1.2**
Relevant Equation(s)	**8, 13**
Source of Data	
Data Requirements	**Default: 0.24** **Alternative values may be proposed and justified**
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	$\mathbf{EF_{N2O,man}}$
Units	$\mathbf{g\ N_2O.m^{-2}.day^{-1}}$
Description	Emission rate of N2O from slurry with a crust
Relevant Section	**1.3**
Relevant Equation(s)	**19**
Source of Data	
Data Requirements	**Default: 0.8** **Alternative values may be proposed and justified.**
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	**EF_{fec}**
Units	**kg CH_4.kg feces^{-1}**
Description	Emission factor for feces on pasture/grassland/rangeland
Relevant Section	**1.2**
Relevant Equation(s)	**17**
Source of Data	
Data Requirements	**Default: 0.000086** **Alternative values may be proposed and justified.**
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	**FEC**
Units	**Kg**
Description	Daily fecal production by grazing animals
Relevant Section	**1.2**
Relevant Equation(s)	**17**
Source of Data	
Data Requirements	**Literature values may be used where applicability can be justified.** **Can be derived from digestibility and intake. Digestibility optimally from laboratory results but intake will most often be literature derived.**
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	**F_{TAN}**
Units	**mmol kg^{-1}**
Description	Concentration of NH_4^+ and NH_3 in slurry
Relevant Section	**1.2**
Relevant Equation(s)	**16**
Source of Data	**Laboratory analysis**
Data Requirements	
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	**Mass of N excreted**
Units	**Kg**
Description	Mass of N excreted
Relevant Section	**1.3**
Relevant Equation(s)	
Source of Data	**Derived from laboratory analysis of feces or literature where justifiable.**
Data Requirements	
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	**n_{eff}**
Units	**%**

Description	Efficiency of collection of methane from enclosed storage
Relevant Section	**1.2**
Relevant Equation(s)	**12**
Source of Data	
Data Requirements	**Measured**
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	P_{TS}
Units	**Kg TS.kg manure**$^{-1}$
Description	Total solid content of manure
Relevant Section	**1.2**
Relevant Equation(s)	**9**
Source of Data	**Derived from laboratory analysis of feces or literature where justifiable.**
Data Requirements	
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	P_{VS}
Units	**Kg VS.kg total solids**$^{-1}$
Description	Fraction of VS in total solids
Relevant Section	**1.2**
Relevant Equation(s)	**9**
Source of Data	**Defaults:** **Heifers – 0.86** **Dry cows – 0.85** **Lactating cows – 0.84** ***Numbers derived from ASABE*** **Alternative values may be proposed and justified.**
Data Requirements	
Collection Procedure	
Revision Frequency	At each verification
Comments	

2.2 Data for verification

Parameter	A_{barn}
Units	m^2
Description	Floor area covered by manure
Relevant Section	**1.1, 1.2**
Relevant Equation(s)	**7**
Source of Data	
Data Requirements	
Collection Procedure	
Revision Frequency	At each verification

Comments	

Parameter	A_{man}
Units	**kg**
Description	Amount of manure applied on fields
Relevant Section	**1.2**
Relevant Equation(s)	**14**
Source of Data	
Data Requirements	
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	$A_{storage}$
Units	m^2
Description	Exposed surface area of manure storage
Relevant Section	**1.3**
Relevant Equation(s)	**19**
Source of Data	
Data Requirements	
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	M_{manure}
Units	**Kg**
Description	Accumulated mass of manure entering storage
Relevant Section	**1.2**
Relevant Equation(s)	**9**
Source of Data	
Data Requirements	
Collection Procedure	
Revision Frequency	At each verification
Comments	

Parameter	**pH**
Units	
Description	pH of manure
Relevant Section	**1.2**
Relevant Equation(s)	**16**
Source of Data	**Derived from analysis of feces**
Data Requirements	
Collection Procedure	
Revision Frequency	At each verification
Comments	Sampling methodology shall be proposed by the project proponent and shall be subject to approval by the verifier

Parameter	T_a

Units	^oC
Description	Ambient temperature in open lot
Relevant Section	**1.2**
Relevant Equation(s)	**5**
Source of Data	**Measured**
Data Requirements	
Collection Procedure	
Revision Frequency	At a minimum, reported mean monthly temperatures must be used.
Comments	

Parameter	T_b
Units	^oC
Description	Ambient temperature in barn
Relevant Section	**1.1, 1.2**
Relevant Equation(s)	**4, 8**
Source of Data	**Measured**
Data Requirements	
Collection Procedure	
Revision Frequency	At a minimum temperature shall be measured daily and a monthly mean taken.
Comments	

Parameter	T_k
Units	^oK
Description	Ambient temperature of stored slurry
Relevant Section	**1.2**
Relevant Equation(s)	**10**
Source of Data	**Measured**
Data Requirements	
Collection Procedure	
Revision Frequency	At a minimum temperature shall be measured weekly and a monthly mean taken.
Comments	

Parameter	T_m
Units	^oC
Description	Ambient temperature of manure
Relevant Section	**1.2**
Relevant Equation(s)	**6**
Source of Data	**Measured**
Data Requirements	
Collection Procedure	
Revision Frequency	At a minimum temperature shall be measured weekly and a monthly mean taken.
Comments	

Parameter	VS_{lossT}
Units	**Kg**
Description	Accumulated loss of volatile solids from manure in storage
Relevant Section	**1.2**
Relevant Equation(s)	**9**

Source of Data	**Measured**
Data Requirements	
Collection Procedure	
Revision Frequency	At each verification
Comments	