Enhanced Livestock Characterization: Implementing IPCC Guidelines & CRT Population

Dr. Kenna Rewcastle

U.S. Environmental Protection Agency | AFOLU Inventory Coordinator

Capacity Building Program for Indian Experts on National Greenhouse Gas Inventory Preparation

25 April 2024 – 1 May 2024, Indian Institute of Technology Gandhinagar, Gujarat, India

Livestock Emissions in India's TNC

- According to TNC Key Category Analysis, these livestock categories are considered "key" categories in level and trend analysis:
  - 3A1: CH_4 from Enteric Fermentation (7% of overall emissions)
  - 3A1: N_2O from Manure Management (1% of overall emissions)

- Transitioning to AR5 GWPs (for CH_4, GWP 21 -> GWP 28), CH_4 from Manure Management might also be elevated to a key category for BTR

Introduction to Livestock Emissions Calculations

Livestock Emissions (CH_4, N_2O) = Activity Data × Emission Factor

Activity Data ↓

Tier 1: Livestock Population Numbers per Subcategory (AAP)

BASIC LIVESTOCK CHARACTERIZATION (TIER 1)

- **Two data components:**
  1. List of livestock categories
  2. Average annual population (AAP)

Two types of livestock populations:

Static population = animals that are alive for the entire year (e.g. dairy cows, layer chickens)

Growing population = animals are alive for less than a full year (e.g. animals grown for meat)

Static Population:

$$\boldsymbol{AAP = NAPA}$$

Growing population:

$$\boldsymbol{AAP = Days\ Alive \times \left(\frac{NAPA}{365}\right)}$$

NAPA = number of animals produced annually

IPCC, 2006: Vol. 4 Equation 10.1

Example: Average Annual Population Calculation

- Broiler chickens → grown in flocks for 60 days before slaughter for meat production

  → Days Alive

- An operation produces 60,000 chickens in one year → NAPA

$$\boldsymbol{AAP = Days\ Alive \times \left(\frac{NAPA}{365}\right)}$$

$$AAP = 60 \times \left(\frac{60{,}000}{365}\right)$$

$$AAP = 9{,}863\ chickens$$

Moving to Tier 2: Enhanced Livestock Characterization + Feed Intake

Livestock Emissions (CH_4, N_2O) = Activity Data × Emission Factor

Activity Data:

- Livestock Population Numbers per Subcategory (AAP)
- \+ Feed Intake per Subcategory (GE or DMI) — Tier 2

Enhanced characterization:

Disaggregate livestock populations **by key breeds/age classes** with unique physiological characteristics.

Can also disaggregate by **region**!

ENHANCED CATTLE CHARACTERIZATION IN INDIA

- Cattle (other)
  - Crossbred Males
    - <1.5 yr
    - >1.5 yr (breeding)
    - >1.5 yr (working)
    - >1.5 yr (breeding + workin
    - >1.5 yr (other)
  - Crossbred Females
    - <1 yr
    - 1-2.5 yr
    - >2.5 yr (milk)
    - >2.5 yr (dry)
    - >2.5 yr (not calved)
    - >2.5 yr (other)
  - Indigenous M es
    - 2 yr
    - g)
    - (milk)
    - >3 y (dry)
    - >3 yr (not calved)
    - >3 yr (other)

22 cattle subcategories x 35 states = **770** cattle populations!

Documenting Activity data in CRT 3A

- Link to USA CRTs for sectoral background table: 3A

- Note: Activity data is entered at national level! Sum all state population numbers to enter national livestock population numbers per subcategory

Moving to Tier 2: Enhanced Livestock Characterization + Feed Intake

Livestock Emissions (CH_4, N_2O) = Activity Data × Emission Factor

Livestock Population Numbers per Subcategory (AAP)

+

Tier 2

Feed Intake per Subcategory (GE or DMI)

Feed intake estimation:

Estimated using **gross energy (GE)** expenditure equations or **dry matter intake (DMI**, simplified Tier 2) from the IPCC guidelines

TIER 2 FEED INTAKE ESTIMATION: GROSS ENERGY

- **Gross energy (GE):** Annual performance and diet data are used to estimate feed intake (MJ/day) an animal needs for maintenance and activities such as growth, lactation, pregnancy, and draught work.

EQUATION 10.16
GROSS ENERGY FOR CATTLE/BUFFALO AND SHEEP

$$GE = \left[\frac{\left(\frac{NE_m + NE_a + NE_l + NE_{work} + NE_p}{REM} \right) + \left(\frac{NE_g + NE_{wool}}{REG} \right)}{\frac{DE\%}{100}} \right]$$

Where:

GE = gross energy, MJ day^{-1}

NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day^{-1}

NE_a = net energy for animal activity (Equations 10.4 and 10.5), MJ day^{-1}

NE_l = net energy for lactation (Equations 10.8, 10.9, and 10.10), MJ day^{-1}

NE_{work} = net energy for work (Equation 10.11), MJ day^{-1}

NE_p = net energy required for pregnancy (Equation 10.13), MJ day^{-1}

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation 10.14)

NE_g = net energy needed for growth (Equations 10.6 and 10.7), MJ day^{-1}

NE_{wool} = net energy required to produce a year of wool (Equation 10.12), MJ day^{-1}

REG = ratio of net energy available for growth in a diet to digestible energy consumed (Equation 10.15)

DE% = digestible energy expressed as a percentage of gross energy

Tier 2 Feed Intake Estimation: Gross Energy

- **Defaults exist for most of these parameters!**
- **Need:**
  - Percent of population lactating, breeding, pregnant
  - Feeding situation (stall, pasture, rangeland)
  - Mature weight
  - Average live weight,
  - Feed digestible energy

Equation 10.16
Gross energy for cattle/buffalo and sheep

$$GE = \left[\frac{\left(\frac{NE_m + NE_a + NE_l + NE_{work} + NE_p}{REM} \right) + \left(\frac{NE_g + NE_{wool}}{REG} \right)}{\frac{DE\%}{100}} \right]$$

Where:

GE = gross energy, MJ day^{-1}

NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day^{-1}

NE_a = net energy for animal activity (Equations 10.4 and 10.5), MJ day^{-1}

NE_l = net energy for lactation (Equations 10.8, 10.9, and 10.10), MJ day^{-1}

NE_{work} = net energy for work (Equation 10.11), MJ day^{-1}

NE_p = net energy required for pregnancy (Equation 10.13), MJ day^{-1}

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation 10.14)

NE_g = net energy needed for growth (Equations 10.6 and 10.7), MJ day^{-1}

NE_{wool} = net energy required to produce a year of wool (Equation 10.12), MJ day^{-1}

REG = ratio of net energy available for growth in a diet to digestible energy consumed (Equation 10.15)

DE%= digestible energy expressed as a percentage of gross energy

Tier 2 Feed Intake Estimation: Gross Energy

- **Defaults exist for most of these parameters!**
- **Need:**
  - Percent of population lactating, breeding, pregnant
  - Feeding situation (stall, pasture, rangeland)
  - Average hours work/day
  - Mature weight
  - Average live weight,
  - Feed digestible energy

Equation 10.16
Gross energy for cattle/buffalo and sheep

$$GE = \left[\frac{\left(\frac{NE_m + NE_a + NE_l + NE_{work} + NE_p}{REM} \right) + \left(\frac{NE_g + NE_{wool}}{REG} \right)}{\frac{DE\%}{100}} \right]$$

Where:

GE = gross energy, MJ day^{-1}

NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day^{-1}

NE_a = net energy for animal activity (Equations 10.4 and 10.5), MJ day^{-1}

NE_l = net energy for lactation (Equations 10.8, 10.9, and 10.10), MJ day^{-1}

NE_{work} = net energy for work (Equation 10.11), MJ day^{-1}

NE_p = net energy required for pregnancy (Equation 10.13), MJ day^{-1}

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation 10.14)

NE_g = net energy needed for growth (Equations 10.6 and 10.7), MJ day^{-1}

NE_{wool} = net energy required to produce a year of wool (Equation 10.12), MJ day^{-1}

REG = ratio of net energy available for growth in a diet to digestible energy consumed (Equation 10.15)

DE%= digestible energy expressed as a percentage of gross energy

SIMPLIFIED TIER 2 FEED INTAKE ESTIMATION: DMI

- **Dry matter intake (DMI):** Predict DMI (kg day-1) from animal body weight and dietary net energy concentration (NEma) or digestible energy (DE%)
  - NEma used to convert feed intake into MJ/day to derive GE for use in enteric fermentation emission factor equation

EQUATION 10.18b
ESTIMATION OF DRY MATTER INTAKE FOR MATURE DAIRY COWS

$$DMI = \left[\frac{\left(\frac{(5.4 \bullet BW)}{500} \right)}{\left(\frac{(100 - DE\%)}{100} \right)} \right]$$

SIMPLIFIED TIER 2 FEED INTAKE ESTIMATION: DMI

- **Dry matter intake (DMI):** Predict DMI (kg day-1) from animal body weight and dietary net energy concentration (NEma) or digestible energy (DE%)
  - NEma used to convert feed intake into MJ/day to derive GE for use in enteric fermentation emission factor equation

EQUATION 10.17
ESTIMATION OF DRY MATTER INTAKE FOR GROWING AND FINISHING CATTLE

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.2444 \bullet NE_{ma} - 0.0111 \bullet NE_{ma}^{2} - 0.472\right)}{NE_{ma}} \right]$$

Where:

DMI = dry matter intake, kg day^{-1}

BW = live body weight, kg

NE_{ma} = estimated dietary net energy concentration of diet or default values in Table 10.8, MJ kg^{-1}

Simplified Tier 2 Feed Intake Estimation: DMI

- **Dry matter intake (DMI):** Predict DMI (kg day-1) from animal body weight and dietary net energy concentration (NEma) or digestible energy (DE%)
  - NEma used to convert feed intake into MJ/day to derive GE for use in enteric fermentation emission factor equation

Equation 10.17

Estimation of dry matter intake for growing and finishing catti

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.2444 \bullet NE_{ma} - 0.0111 \bullet NE_{ma}^{2} - 0.472\right)}{NE_{ma}} \right]$$

Where:

DMI = dry matter intake, kg day^{-1}

BW = live body weight, kg

NE_{ma} = estimated dietary net energy concentration of diet or default values in Table 10.

Table 10.8

Examples of NE_{MA} content of typical diets fed to cattle for estimation of dry matter intake in Equations 10.17 and 10.18

Diet type	NE_{ma} (MJ (kg dry matter)$^{-1}$)
High grain diet > 90%	7.5 - 8.5
High quality forage (e.g., vegetative legumes & grasses)	6.5 - 7.5
Moderate quality forage (e.g., mid season legume & grasses)	5.5 - 6.5
Low quality forage (e.g., straws, mature grasses)	3.5 - 5.5

Source: Estimates obtained from predictive models in NRC (1996), NE_{ma} can also be estimated using the equation: NE_{ma} = REM x 18.45 x DE% / 100.

Simplified Tier 2 Feed Intake Estimation: DMI

- **Dry matter intake (DMI):** Predict DMI (kg day-1) from animal body weight and dietary net energy concentration (NEma) or digestible energy (DE%)

Equation 10.17

Estimation of dry matter intake for growing and finishing cattle

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.2444 \bullet NE_{ma} - 0.0111 \bullet NE_{ma}^{2} - 0.472\right)}{NE_{ma}} \right]$$

$$NE_{ma} = REM \times 18.45 \times DE\% / 100.$$

Equation 10.14

Ratio of net energy available in a diet for maintenance to digestible energy consumed

$$REM = \left[1.123 - \left(4.092 \bullet 10^{-3} \bullet DE\%\right) + \left[1.126 \bullet 10^{-5} \bullet (DE\%)^{2}\right] - \left(\frac{25.4}{DE\%}\right) \right]$$

GE vs. DMI: Pros and Cons

Gross Energy

- Greater data requirement
- Allows for more accurate emissions calculation due to pregnancy, milk production, work (*India's livestock characterization provides this data!)*
- Many defaults exist
- Creates opportunities for improvement to develop country-specific GE parameters
- Supported by ALU and IPCC software

Dry Matter Intake

- Only requires animal weight and DE%
- Does not account for differences in emissions due to energy needed for activities such as lactation, pregnancy, work
- Not supported by ALU or the IPCC software (with DE% workaround for NEma) → requires development of spreadsheets

Documenting GE Data in CRT 3As

- Link to USA CRTs for sectoral background table supplement: 3As

- Note: Factors such as weight, GE, etc. can be reported at the national level and by aggregated subcategories (i.e. all Indigenous female cattle, etc.) by weighting these parameters by livestock population numbers in each state/subcategory.

Manure Management Data

- For each livestock subcategory/population (possibly disaggregated by state as well), you need information on the **% of manure produced** by that animal type that is **managed in each manure management system**.
  - Can use expert **judgement**!

Manure Management Systems

Table 10.18 **Definitions of manure management systems**	
System	**Definition**
Pasture/Range/Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Solid storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically.
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
Uncovered anaerobic lagoon	A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields.
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.

Anaerobic digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4, which is captured and flared or used as a fuel.
Burned for fuel	The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel.
Cattle and Swine deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.
Composting - in-vessel[a]	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.
Composting - Static pile[a]	Composting in piles with forced aeration but no mixing.
Composting - Intensive windrow[a]	Composting in windrows with regular (at least daily) turning for mixing and aeration.
Composting - Passive windrow[a]	Composting in windrows with infrequent turning for mixing and aeration.
Poultry manure with litter	Similar to cattle and swine deep bedding except usually not combined with a dry lot or pasture. Typically used for all poultry breeder flocks and for the production of meat type chickens (broilers) and other fowl.
Poultry manure without litter	May be similar to open pits in enclosed animal confinement facilities or may be designed and operated to dry the manure as it accumulates. The latter is known as a high-rise manure management system and is a form of passive windrow composting when designed and operated properly.
Aerobic treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration. Natural aeration is limited to aerobic and facultative ponds and wetland systems and is due primarily to photosynthesis. Hence, these systems typically become anoxic during periods without sunlight.

[a] Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

Manure Management Systems

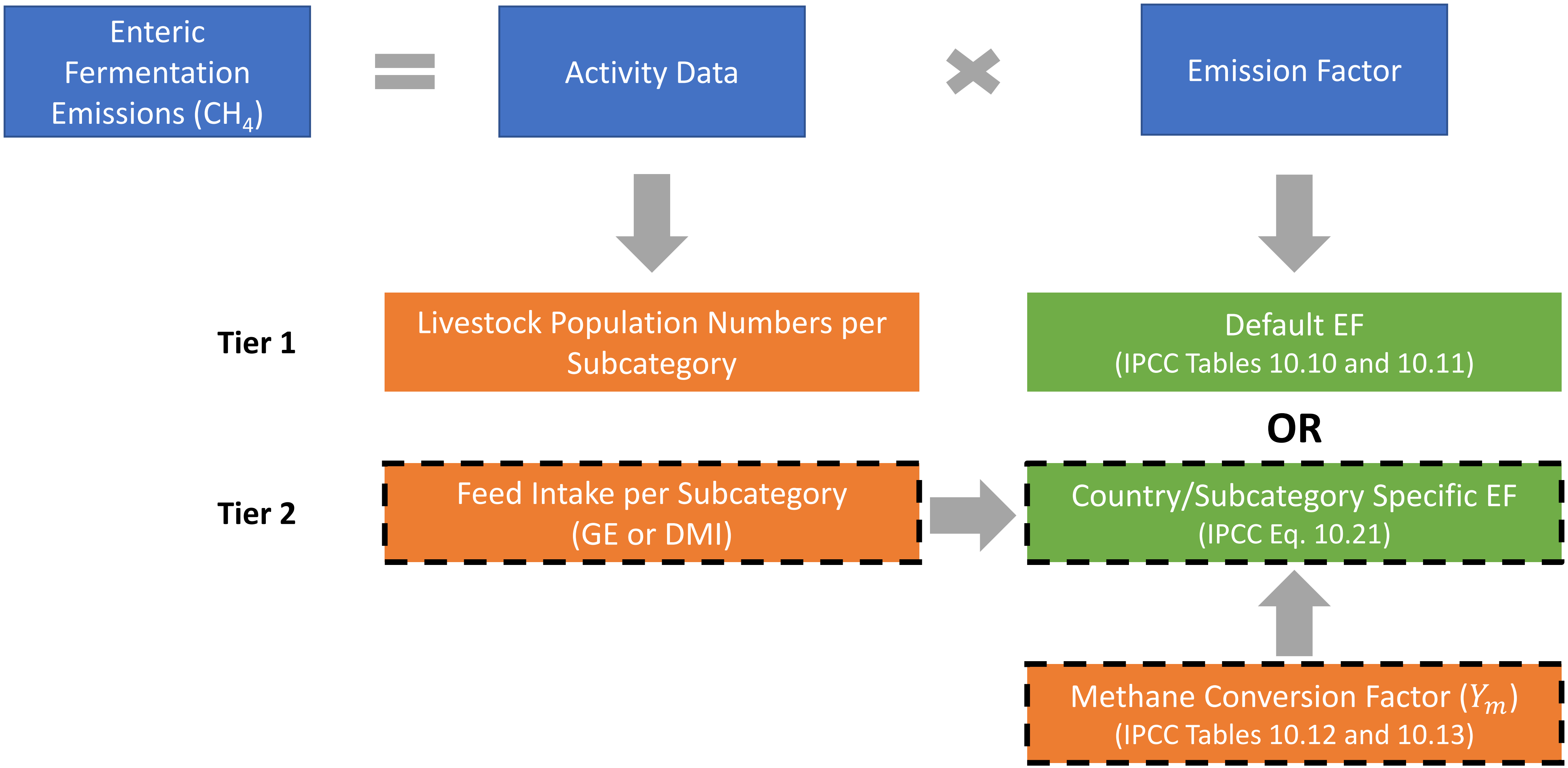
- From Dr. Mondal's presentation:
  - Manure stored in cakes, pasture, heaps
  - Methane emissions from cakes: Tier 1
  - Nitrous oxide emissions from manure management: Tier 2

- Heaps are likely "solid storage" from previous slide
- Cakes are likely manure deposited in pastures/range/paddock (accounted for in agriculture soil management as a direct fertilizer input)

Exercise: livestock Characterization in ALU

- Demonstrate entry of state-level data
- Today's exercise will use national-level data due to time constraints
- Will use enhanced characterization for indigenous female populations, and indigenous mature male populations that are used as draught animals
- All others will use basic characterization and Tier 1 estimates (including buffalo, goats, and other livestock populations)

Enteric Fermentation (3A1): Tier 2



Tier 2 Enteric Fermentation Emission Factors

Equation 10.21

CH_4 emission factors for enteric fermentation from a livestock category

$$EF = \left[\frac{GE \bullet \left(\frac{Y_m}{100} \right) \bullet 365}{55.65} \right]$$

Where:

EF = emission factor, kg CH_4 head^{-1} yr^{-1}

GE = gross energy intake, MJ head^{-1} day^{-1}

Y_m = methane conversion factor, per cent of gross energy in feed converted to methane

The factor 55.65 (MJ/kg CH_4) is the energy content of methane

Methane Conversion Factors

- IPCC 2006 Guidelines provide default values, but IPCC 2019 Refinement provide updated defaults with more granularity

IPCC 2019 Refinement Default Y_M or MY Values

Table 10.12 (Updated)[6]
Cattle/buffalo methane conversion factors (Y_M)

Livestock category	Description	Feed quality Digestibility (DE %) and Neutral Detergent Fibre (NDF, % DMI)	MY, g CH_4 kg DMI^{-1}	Y_m[3]
[1,4]Dairy cows and Buffalo	High-producing cows[5] (>8500 kg/head/yr^{-1})	DE ≥ 70 NDF ≤ 35	19.0	5.7
	High-producing cows[5] (>8500 kg/head/yr^{-1})	DE ≥ 70 NDF ≥ 35	20.0	6.0
	Medium producing cows (5000 – 8500 kg yr^{-1})	DE 63-70 NDF > 37	21.0	6.3
	Low producing cows (<5000 kg yr^{-1})	DE ≤ 62 NDF >38	21.4	6.5
[2]Non dairy and multi-purpose Cattle and Buffalo	> 75 % forage	DE ≤ 62	23.3	7.0
	Rations of >75% high quality forage and/or mixed rations, forage of between 15 and 75% the total ration mixed with grain, and/or silage.	DE 62–71	21.0	6.3
	Feedlot (all other grains, 0-15% forage)	DE ≥ 72	13.6	4.0
	Feedlot (steam-flaked corn, ionophore supplement - 0-10% forage)	DE > 75	10.0	3.0

Source: IPCC 2019 Refinement Vol. 4

Tier 2: CH4 Emissions From Manure Management

Equation 10.23
CH_4 emission factor from manure management

$$EF_{(T)} = \left(VS_{(T)} \bullet 365\right) \bullet \left[B_{o(T)} \bullet 0.67\, kg/m^3 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet MS_{(T,S,k)} \right]$$

Where:

$EF_{(T)}$ = annual CH_4 emission factor for livestock category T, kg CH_4 animal^{-1} yr^{-1}

$VS_{(T)}$ = daily volatile solid excreted for livestock category T, kg dry matter animal^{-1} day^{-1}

365 = basis for calculating annual VS production, days yr^{-1}

$B_{o(T)}$ = maximum methane producing capacity for manure produced by livestock category T, m^3 CH_4 kg^{-1} of VS excreted

0.67 = conversion factor of m^3 CH_4 to kilograms CH_4

$MCF_{(S,k)}$ = methane conversion factors for each manure management system S by climate region k, %

$MS_{(T,S,k)}$ = fraction of livestock category T's manure handled using manure management system S in climate region k, dimensionless

India has this data! Defaults exist for all other parameters.

Direct vs. Indirect N_2O Emissions from Manure Mgmt.

- **Direct N_2O emissions:**
  - Nitrous oxide released directly from nitrification/dentification of N in manure
  - *Emissions vary with:*
    - N and C content of manure
    - Duration of storage
    - Type of manure treatment
    - Manure storage conditions (oxygen availability, pH, moisture)
- ***Indirect N_2O emissions:***
  - Volatilization of ammonia and NOx from manure
  - Runoff and leaching of N into soils from solid/liquid storage of manure outdoors

Source: Illinois Times

Direct N_2O Emissions from Manure Management

Direct N_2O Emissions from Manure Mgmt. = Activity Data × Emission Factor

Tier 1

Activity Data:

- Livestock Population Numbers per Subcategory
- Nitrogen Excretion Rate (Nex) (Defaults: IPCC 2019 Ref. Table 10.19)
- Fraction of Total N Excreted Per Manure Mgmt. System (MS)

Emission Factor:

- Default EF per Manure Mgmt. Sys. (IPCC 2019 Ref. Table 10.21)

Direct N_2O Emissions from Manure Management

Equation 10.25
Direct N_2O emissions from manure management

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right) \right] \bullet EF_{3(S)} \right] \bullet \frac{44}{28}$$

Where:

$N_2O_{D(mm)}$ = direct N_2O emissions from Manure Management in the country, kg N_2O yr^{-1}

$N_{(T)}$ = number of head of livestock species/category *T* in the country

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* in the country, kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$EF_{3(S)}$ = emission factor for direct N_2O emissions from manure management system *S* in the country, kg N_2O-N/kg N in manure management system *S*

S = manure management system

T = species/category of livestock

44/28 = conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

Default Nex Values: 2019 IPCC Refinement Vol. 4 Chap. 10

Table 10.19 (Updated)
Default values for Nitrogen excretion rate (kg N (1000 kg animal mass)$^{-1}$ day^{-1})

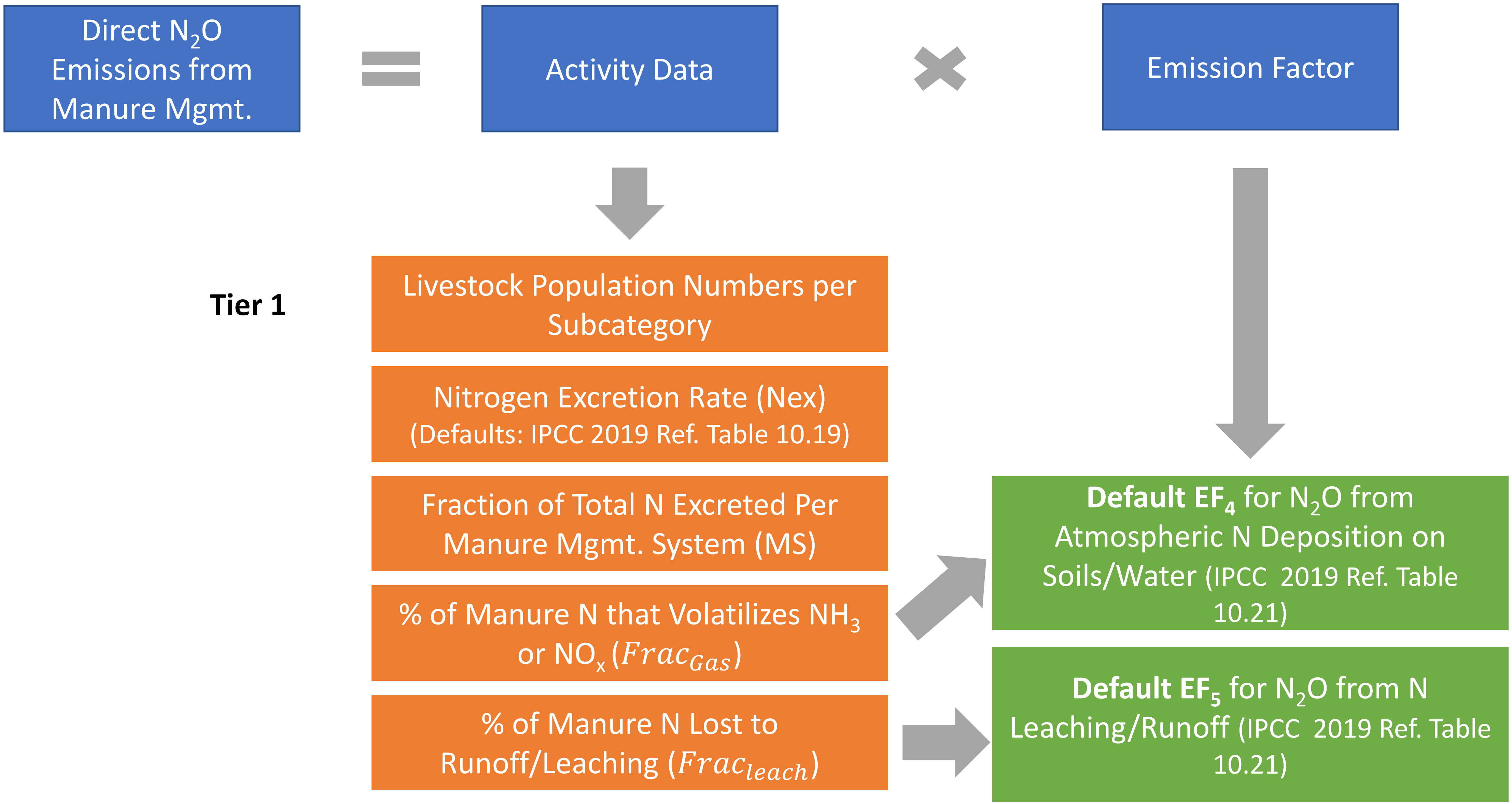
Category of animal	Region																		
	North America	Western Europe	Eastern Europe	Oceania	Latin America			Africa			Middle East			Asia			India sub-continent		
					Mean	High PS[1]	Low PS[1]	Mean	High PS	Low PS	Mean	High PS	Low PS	Mean	High PS	Low PS	Mean	High PS	Low PS
Dairy cattle[3]	0.60	0.50	0.42	0.72	0.39	0.60	0.28	0.44	0.41	0.45	0.50	0.49	0.51	0.44	0.55	0.41	0.65	0.51	0.70
Other cattle[3]	0.40	0.42	0.47	0.46	0.31	0.36	0.29	0.44	0.42	0.45	0.55	0.51	0.58	0.38	0.36	0.38	0.44	0.63	0.40
Buffalo[3]	NA	0.45	0.35	NA	0.41			0.41			0.39			0.44			0.57		
Swine[4]	0.39	0.65	0.63	0.54	0.59	0.55	0.67	0.44	0.33	0.49	0.66	0.67	0.56	0.61	0.54	0.67	0.68	0.63	0.71
Finishing	0.46	0.76	0.77	0.72	0.73	0.69	0.80	0.49	0.39	0.54	0.73	0.75	0.60	0.70	0.63	0.76	0.76	0.74	0.76
Breeding	0.24	0.38	0.36	0.31	0.35	0.32	0.43	0.29	0.21	0.35	0.40	0.41	0.37	0.37	0.32	0.43	0.43	0.37	0.47

Default EF: 2019 IPCC Refinement Vol. 4 Chap. 10

Table 10.21 (Updated)
Default emission factors for direct N_2O emissions from manure management[24]

System	Definition	EF_3 [kg N_2O-N (kg Nitrogen excreted)$^{-1}$]
Pasture/Range/ Paddock	The manure from pasture and range grazing animals is allowed to lie as is, and is not managed.	Direct and indirect N_2O emissions associated with the manure deposited on agricultural soils and pasture, range, paddock systems are treated in Chapter 11, Section 11.2, N_2O emissions from managed soils.
Daily spread[5]	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion. N_2O emissions during storage and treatment are assumed to be zero. N_2O emissions from land application are covered under the Agricultural Soils category.	0
Solid storage[2, 4, 6]	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.	0.010
Solid storage-Covered/compacted[4, 7]	Similar to solid storage, but the manure pile is a) covered with a plastic sheet to reduce the surface of manure exposed to air and/or b) compacted to increase the density and reduce the free air space within the material.	0.01
Solid storage - Bulking agent addition[4, 8]	Specific materials (bulking agents) are mixed with the manure to provide structural support. This allows the natural aeration of the pile, thus enhancing decomposition. (e.g. sawdust, straw, coffee husks, maize stover)	0.005
Solid storage – Additives[4, 8]	The addition of specific substances to the pile in order to reduce gaseous emissions. Addition of certain compounds such as attapulgite, dicyandiamide or mature compost have shown to reduce N_2O emissions; while phosphogypsum reduce CH_4 emissions	0.005
Dry lot[9]	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically. Dry lots are most typically found in dry climates but also are used in humid climates.	0.02

INDIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT



Indirect N_2O Emissions from Manure Mgmt.: Volatilization

Equation 10.26
N losses due to volatilisation from manure management

$$N_{volatilization-MMS} = \sum_S \left[\sum_T \left[\left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right) \bullet \left(\frac{Frac_{GasMS}}{100} \right)_{(T,S)} \right] \right]$$

Where:

$N_{volatilization\text{-}MMS}$ = amount of manure nitrogen that is lost due to volatilisation of NH_3 and NO_x, kg N yr^{-1}

$N_{(T)}$ = number of head of livestock species/category *T* in the country

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* in the country, kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$Frac_{GasMS}$ = percent of managed manure nitrogen for livestock category *T* that volatilises as NH_3 and NO_x in the manure management system *S*, %

Equation 10.27
Indirect N_2O emissions due to volatilisation of N from manure management

$$N_2O_{G(mm)} = \left(N_{volatilization-MMS} \bullet EF_4 \right) \bullet \frac{44}{28}$$

Where:

$N_2O_{G(mm)}$ = indirect N_2O emissions due to volatilization of N from Manure Management in the country, kg N_2O yr^{-1}

EF_4 = emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilised)$^{-1}$; default value is 0.01 kg N_2O-N (kg NH_3-N + NO_x-N volatilised)$^{-1}$, given in Chapter 11, Table 11.3

Indirect N_2O Emissions from Manure: Leaching/Runoff

Equation 10.28
N losses due to leaching from manure management systems

$$N_{leaching-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)}\right) \bullet \left(\frac{Frac_{leachMS}}{100}\right)_{(T,S)}\right]\right]$$

Where:

$N_{leaching\text{-}MMS}$ = amount of manure nitrogen that leached from manure management systems, kg N yr^{-1}

$N_{(T)}$ = number of head of livestock species/category *T* in the country

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* in the country, kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$Frac_{leachMS}$ = percent of managed manure nitrogen losses for livestock category *T* due to runoff and leaching during solid and liquid storage of manure (typical range 1-20%)

Equation 10.29
Indirect N_2O emissions due to leaching from manure management

$$N_2O_{L(mm)} = \left(N_{leaching-MMS} \bullet EF_5\right) \bullet \frac{44}{28}$$

Where:

$N_2O_{L(mm)}$ = indirect N_2O emissions due to leaching and runoff from Manure Management in the country, kg N_2O yr^{-1}

EF_5 = emission factor for N_2O emissions from nitrogen leaching and runoff, kg N_2O-N/kg N leached and runoff (default value 0.0075 kg N_2O-N (kg N leaching/runoff)$^{-1}$, given in Chapter 11, Table 11.3

Default $Frac_{GAS}$ and $Frac_{LEACH}$: 2019 IPCC Refinement Vol. 4 Chap. 10

Table 10.22 (Updated)
Default values for nitrogen loss fractions due to volatilisation of NH_3 and NO_x and leaching of nitrogen from manure management

System	Applicable System Variation	Swine		Dairy Cow		Poultry		Other Cattle		Other animals	
		[1]$Frac_{Gas\_MS}$	[2,5]$Frac_{leach\_MS}$	$Frac_{Gas\_MS}$	[2,5]$Frac_{leach\_MS}$	$Frac_{Gas\_MS}$	[2,5]$Frac_{leach\_MS}$	$Frac_{Gas\_MS}$	[2,5]$Frac_{leach\_MS}$	$Frac_{Gas\_MS}$	[2,5]$Frac_{leach\_MS}$
Uncovered anaerobic lagoon		0.40 (0.25 – 0.75)	0	0.35 (0.20 – 0.80)	0	0.40 (0.25 – 0.75)	0	0.35 (0.20 – 0.80)	0	*0.35 (0.20 – 0.80)*	0
Liquid/Slurry	With natural crust cover	0.30 (0.09 – 0.36)	0	0.30 (0.09 – 0.36)	0	NO	0	0.30 (0.09 – 0.36)	0	*0.09*	0
	Without natural crust cover	0.48 (0.15 – 0.60)	0	0.48 (0.15 – 0.60)	0	*0.40 (0.25 – 0.75)*	0	0.48 (0.15 – 0.60	0	*0.15*	0
	With cover	0.10 (0.03 – 0.12)	0	0.10 (0.03 – 0.12)	0	0.08 (0.05-0.15)	0	0.10 (0.03 – 0.12)	0	*0.03*	0
Pit storage below animal confinements		0.25 (0.15 – 0.30)	0	0.28 (0.10 – 0.40)	0	*0.28 (0.10 – 0.40)*	0	*0.25 (0.15 – 0.30)*	0	*0.25 (0.15 – 0.30)*	0
Daily spread		0.07 (0.05 – 0.60)	0	0.07 (0.05 – 0.60)	0	*0.07 (0.05 – 0.60)*	0	*0.07 (0.05 – 0.60)*	0	*0.07 (0.05 – 0.60)*	0

Default EFs: 2019 IPCC Refinement Vol. 4 Chap. 11

Table 11.3 (Updated)
Default emission, volatilisation and leaching factors for indirect soil N_2O emissions

Emission factor	Aggregated		Disaggregated		
	Default value	Uncertainty range	Disaggregation	Default value	Uncertainty range
EF_4 [N volatilisation and re-deposition][1], kg N_2O–N (kg NH_3–N + NO_X–N volatilised)$^{-1}$	0.010	0.002 - 0.018	Wet climate	0.014	0.011 – 0.017
			Dry climate	0.005	0.000 – 0.011
EF_5 [leaching/runoff][2], kg N_2O–N (kg N leaching/runoff)$^{-1}$	0.011	0.000 - 0.020	-	-	-