

Budgeting anthropogenic greenhouse gas emission from Indian livestock using country-specific emission coefficients

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Greenhouse gas (GHG) emissions from the livestock sector are confined to enteric fermentation and manure management. The present inventory is focused on estimation of GHGs using country-specific emission factors for ruminants based on Indian Feeding Standards as a measure of gross energy intake. The thrust is on uncertainty reduction by adopting country-specific animal performance data leading to the development of more refined emission factors. The estimated GHG emission is 9.0 Tg methane and 1 Gg nitrous oxide for the year 1997, and in terms of CO₂ equivalent it is around 190 Tg. Methane emission is the dominant one, while nitrous oxide is negligible. Enteric fermentation is the major source of methane, accounting for 90% of total methane compared to 10% from manure management. Ruminants, especially bovines are the largest source (91%). The estimate also highlights hotspots, emission density, methane emissions from dairy and non-dairy bovines, milk yield vs methane, which are useful in formulating mitigation strategies. The abatement option in the Indian context is also highlighted.

Keywords: GHG emission, emission coefficients, enteric fermentation, livestock, manure management.

'GLOBAL warming' or 'global climate change' has become a major concern due to increase in atmospheric concentration of greenhouse gases (GHGs) over the last century, mainly due to anthropogenic activities. Keeping this concern in mind, Indian scientists have been estimating emissions from anthropogenic sources such as energy and transformation sectors, industrial processes, agricultural activities, land use, land use change, and forestry and waste. Though the GHG components include a basket of six GHGs (CO₂, CH₄, N₂O, NO_x, CO and CFCs), CO₂, CH₄ and N₂O are the predominant and aggregate emissions of these gases due to anthropogenic activities from India and are estimated to be around 1,228,540 Gg for the year 1994, according to official estimation¹. Sixty-one per cent of the emissions come from fossil-fuel combustion and 28% from agricultural activities such as livestock rearing, manure, management, rice cultivation, burning of crop residues, etc. In the agriculture sector, livestock rearing is the major emitter and accounts for 78% of total methane emission from the agriculture sector and about 50% of methane emission from all sectors¹.

Livestock scenario

Livestock wealth of India is one of the largest in the world. India ranks first among cattle, buffalo and goat population and fifth in sheep population. Livestock rearing is an integral part of the agriculture system in India. Livestock includes cattle, buffaloes, sheep, goats, pigs, horses, mules, donkeys, camels and poultry. However, bovines and small ruminants are the most dominant feature of the agrarian scene and are also the major source of GHG emission. India is home to 28 well-defined categories of cattle and eight categories of buffalo. However, bulk of the cattle (90%) is non-descript, low producing, indigenous breed. Even in the case of buffaloes, high-producing animals are less (10–20%). Most of the agricultural operations and rural transporting system are dependent on animal power. The combination of livestock rearing and crop production enables fuller utilization of farm by-products, conserves soil fertility, increases income and generates employment. Maintenance of bovines is not only a concurrent occupation of rural families having land, but also for those who are landless. Livestock scenario, land utilization pattern, availability of feed and fodder have been discussed elsewhere^{2–6}.

Livestock emissions

GHG emissions from livestock have two components: (a) Methane emission from enteric fermentation and manure

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management. (b) Nitrous oxide from animal waste management system.

Methane emission

Enteric fermentation: This is responsible for high emission of methane from ruminants. These animals possess rumen or fore stomach, which allows them to digest large quantities of cellulose and other roughages found in plant material. A small fraction of symbiotic microorganisms (3–10%) is methanogenic bacteria, which produce methane while removing hydrogen from the rumen. Methane is released mainly through eructation and normal respiration and a small quantity as flatus.

Manure management: Livestock manure is principally composed of organic material. When this organic material decomposes in anaerobic environment, methanogenic bacteria produce methane. When manure is stored or treated as a liquid (e.g. in lagoons, ponds, tanks or pits), it tends to decompose anaerobically and produce a significant quantity of methane. When manure is handled as a solid (e.g. in stacks or pits) or deposited on pastures and rangelands, it tends to decompose aerobically and little or no methane is produced.

Nitrous oxide emission

This is due to conversion of manure nitrogen into nitrous oxide during storage. Nitrous oxide is formed when manure nitrogen is nitrified or denitrified. The amount of N_2O released depends on the system and duration of waste management. Emissions of N_2O taking place during storage or handling of manure (i.e. before the manure is added to soil) come under 'manure management', whereas emissions from soil application of manure (dry management system) are considered as 'soil emissions'.

There are three potential sources of N_2O emissions related to animal production. These are (a) animals themselves, (b) animal wastes during storage and treatment, (c) dung and urine deposited by free-range grazing animals. Direct emission from animals is not reported. Only liquid systems (anaerobic lagoons and other liquid system) qualify under manure management. Emissions from stable manure applied to agricultural soil (e.g. daily spread), dung and urine deposited by range grazing animals, and solid storage and dry lot are considered to be emissions from agricultural soil.

Previous work

Most of the reports on GHG emissions are related to methane only. The early works on methane measurements from animals in India are those by Krishna *et al.*⁷, from

bovines in organized farmhouse using face mask technique and regression analysis. They predicted higher quantities of methane emissions from bovine. Murray *et al.*⁸ and Pandey⁹ have reported methane emission of 5 kg in sheep and goats. Recent works on measurement on methane are those of NDRI, Karnal^{5,10}. The methane emission rate is reported to vary from 3 to 6% of gross energy (GE), for cattle and buffalo.

Ahuja¹¹ has estimated methane emissions from domesticated animals to the order of 10.4 Tg for the year 1985 based on default values of methane emission factors. WRI has estimated¹² Indian emissions at 10.0 Tg for the year 1990.

The first official Indian inventory of GHGs from India was prepared in 1991 for the base year 1990, and differed from IPCC estimation of employing data typical to Indian animal wealth, viz. animal body weight, feed intake of different age groups and broadly adopting the Blaxter and Clapperton equation. The emission rates reported vary from 23 to 32 kg (non-descript and crossbred cattle), 26 to 40 kg (non-descript and higher buffalo bred), and 5 kg for goat and sheep^{13–15}.

Swamy and Ramasami¹⁶ updated methane emission from enteric fermentation for the year 1992. They have also correlated methane emission factor to average milk production in dairy cows based on default emission factors from different continents. Methane production is reported to be directly proportional to production of milk. The inventory was again updated in 1998 as part of the ALGAS project¹⁷.

Over the years there has been a periodical refinement in the development of national GHG inventory. Recent reports^{18,19} on estimation of methane from the animal sector broadly adopt methane emission factors (coefficients) developed by Swamy and Ramasami¹⁶ and provide emission coefficients for different age groups. Singh and coworkers^{20–22} have predicted the average methane emission rate to be at 35, 27.5, 35.5, 4.2 and 3.7 kg/animal/yr for cattle (crossbred), cattle (indigenous), buffalo, sheep and goat respectively^{20–22}. Singhal and Madhu Mohini¹⁰ have estimated methane from enteric fermentation based on dry matter estimation. The earlier estimation¹⁸ of nitrous oxide is 11 Gg. There seems to be some discrepancy as emissions from the soil have also been included under livestock.

Though GHG emission estimates have been made since the early nineties in India, uncertainties are still large in all sectors in the inventories of GHGs and the livestock sector is no exception. There have been uncertainties in classification and categorization of animal population, body weight, feed intake, feed habits, feed characteristics, animal nutrition, milk data, emission coefficients, etc., resulting in variation in GHG emission. Considering the rationale for applicability of the IPCC default coefficients to Indian conditions/livestock for budgeting GHGs, it was felt necessary that efforts be made to develop country-specific emission factors which conform to 'good practice

guidance' as recommended by IPCC and IPCC good practice guidance^{23,24}. The latest official estimation by the NATCOM group for the year 1994 is an effort in this direction and has addressed many problems related to uncertainties and reported 10.1 Tg from the animal sector. However, the emission factors derived are the average of three methodologies used for estimation of GE intake, i.e. Indian feed standards, IPCC energy equations and dry matter estimation. The focus of this article is to highlight the country-specific Indian Feeding Standards (IFS) methodology for estimating GE intake and derive emission factors for the year 1997 for which the latest census data are available.

Methodology

Methane from enteric fermentation

Tier-II approach has been adopted for cattle, buffalo, sheep and goat and emission factors, whereas default IPCC emission factors are used for the other animals^{23,24}.

Emission coefficients: The emission coefficients required for emission estimates under Tier-II methodology are the Methane Conversion Factor (MCF) and Methane Emission Factor (MEF).

MCF is the extent to which feed energy (FE) is converted to methane and depends on several interacting feed and animal characteristics. MCF values for the present estimation broadly conform to NDRI emission values and are presented in Table 1, in comparison with IPCC and ALGAS values.

MEF is the average annual emission of methane per animal (kg methane/animal/yr). Derivation of emission factors requires feed intake estimates in terms of GE and requires animal performance data such as categorization and characterization of animal populations and their live weight. Domestic animals have been divided into distinct, relatively homogeneous groups and ruminants (cattle, buffalo, sheep and goat) have been further sub-categorized into sub-groups. The body weights adopted in the present estimation are the same as those adopted by Swamy and Shashirekha²⁵ and Gupta *et al.*²⁶.

The other data (activity data) needed are age, feeding situation (stall-fed or housed, pasture, grazing large areas) production level and performance (maintenance, location, work, breeding, growth, etc.), feed digestibility, milk production, etc. (Table 2). Data are the all-India average and vary from state to state.

Estimation of GE: This has been calculated using appropriate TDN values from tables of Indian feeding standard as recommended by ICAR^{27,28} for bovines. TDN values for each category have been converted to DE and then to GE (MJ) values using appropriate equations/conversion factors.

$$GE \text{ (MJ)} = (TDN_c \times 4.4 \times 4.184 \times 365)/(DE/100)$$

where TDN_c is the variable for different sub-categories.

For example, in the case of milk animals

$$TDN_c = \sum TDN \text{ (maintenance and activity) + lactation + pregnancy.}$$

For non-dairy – working bulls,

$$TDN_c = \sum TDN \text{ (maintenance and activity) + work (h/day).}$$

In case of sheep and goat feed intake has been estimated as dry matter intake of 2.5 to 3% of body weight.

$$\text{Emissions (kg/yr)} = [\text{GE (MJ/day)} \times Y_m \times (365 \text{ days/yr})] / [55.65 \text{ MJ/kg CH}_4],$$

where Y_m is the methane conversion factor.

Total emission is determined by multiplying the number of animals in each category with the emission factor. Emissions from all categories are aggregated and total emission expressed as Gg methane/yr.

Table 1. Categorization of ruminants and comparison of methane conversion factors

Description	NPL*	CLRI**	IPCC	ALGAS
Cattle (indigenous)				
Dairy	4.83	6.00	6 ± 0.5	7.00
Young stock				
Below 1 year	5.00	5.50	6 ± 0.5	7.00
1–3 years	5.43	5.50	6 ± 0.5	7.00
Non-dairy				
Male (working, breeding)	6.00	6.00	7 ± 0.5	7.50
Male others (not working)	4.83	6.00	7 ± 0.5	7.50
Female	4.83	6.00	7 ± 0.5	7.50
Cattle (crossbred)				
Dairy	4.83	6.00	6 ± 0.5	7.00
Young stock				
Below 1 year	4.83	5.50	6 ± 0.5	7.00
1–3 years	4.83	5.50	6 ± 0.5	7.00
Non-dairy				
Male (working, breeding)	4.83	6.00	7 ± 0.5	7.50
Male others (not working)	4.83	6.00	7 ± 0.5	7.50
Female	4.83	6.00	7 ± 0.5	7.50
Buffalo				
Dairy	5.43	6.00	6 ± 0.5	7.00
Young stock				
Below 1 year	3.02	5.50	6 ± 0.5	7.00
1–3 years	3.92	5.50	6 ± 0.5	7.00
Non-dairy				
Male	5.43	6.00	7 ± 0.5	7.50
Female	5.43	6.00	7 ± 0.5	7.50

*Based on NDRI emission factors.

**Based on IPCC and NDRI values.

Table 2. Activity data

Livestock species	Cattle	Buffalo	Sheep	Goat
Body weight – adults (kg)				
Present estimation	175–300	275–300	30.4	30.2
Previous Indian inventories	180–220	200–220	24–26	20–23
IPCC	125–275	200–450	28	30
FAO data on carcass weight (1995)	103	138	12	10
Approx. live weight FAO	148–173	200–230	24–26	20–23

Description	Cattle		Buffalo
	Indigenous	Crossbred	
Other data			
Weight – young stock (kg)	40–140	60–180	70–180
Weight gains/kg/day – young stock (kg)	0.11–0.18	0.19–0.27	0.23–0.25
Feeding situation	Stall-fed/range lands	Stall-fed	Stall-fed/range lands
Dairy – animals in milk	53	69	64
Dairy – dry animals	47	31	36
Milk kg/day – dairy	1.7	5.7	3.6
Fat content – dairy	4.7	4.1	7.4
% Pregnant – dairy	40	50	35
Digestibility of feed (%)	50–60	55–70	50–60
Work hours/day – adult	1.7	0	1.7

Emissions (Gg/yr) = EF (kg/head/yr) × population/
10⁶ kg/Gg.

The emission factor

$$EF_i = VS_i \times 365 \text{ days/yr} \times B_{oi} \times 0.67 \text{ kg/m}^3 \\ \times \sum_{jk} MCF_{jk} \times MS\%_{ijk},$$

Tier-II approach – manure management

The required data are population under different climate regions (cool, temperate and warm), volatile solids (VS), ash content of VS and methane-producing potential of the manure. The animal population of the States and Union Territories has been grouped into cool, temperate and warm regions based on meteorological data from 391 stations in India²⁹. The maximum methane-producing capacity for manure (B_0) is adopted from IPCC guidelines^{23,24}. Data on different manure-management systems (per cent distribution) as adopted by IPCC (1996) for the Indian sub-continent are used.

Estimation of VS: The weighted average of GE intake by dairy (in dry and milk) and non-dairy animals is used in the estimation of VS. The ash content has been taken as 17% for Indian manure³⁰.

$$VS \text{ (kg Dm/day)} = \text{Intake (MJ/day)} \times (1 \text{ kg}/18.45 \text{ MJ}) \\ \times (1 - \text{DE}\%/100) \times (1 - \text{ASH}\%/100),$$

where VS is volatile solid excretion per day on a dry weight basis, Dm is dry matter, Intake is the estimated daily average feed intake in MJ/day, DE% is digestibility of the feed in per cent and ASH% is ash content of the manure in per cent.

where EF_i is the annual emission factor (kg) for animal type i (e.g. dairy cows), VS_i is daily volatile solid excreted (kg) for animal type i , B_{oi} is maximum methane producing capacity (m^3/kg of VS) for manure produced by animal type i , MCF_{jk} are methane conversion factor for each manure management system j by climate region k , and $MS\%_{ijk}$ is fraction of animal type i 's manure handled using manure system j in climate region k .

Step 3 under enteric fermentation has been followed for total estimation.

Nitrous oxide emissions from animal waste management systems

Methodology: The most important parameters for estimation of nitrous oxide are derivation of nitrogen excretion that is generally expressed as kg N/animal/yr. In the absence of any reliable data from the Indian subcontinent, the default values are the most appropriate and useful though there are uncertainties in the values listed in relevant tables of IPCC. According to the guidelines, cattle (dairy and non-dairy), pigs and poultry only account for the nitrous oxide emissions and other animals like sheep, goat, camels, which do not account for manure manage-

ment under wet system, are eliminated from the category of animals producing N_2O from AWMS.

Step 1: Population data same as used for estimation of methane from enteric fermentation and manure management.

Step 2: Nitrogen excretion – Values provided in table 4–20 (IPCC) are used for estimating nitrogen excretion/animal. Dairy cattle – 60, Non-dairy cattle – 40, pigs – 16 and poultry – 60 kg/animal/yr.

Step 3: Nitrogen excretion from AWMS systems (anaerobic lagoon/liquid system and any other system) is derived as percentage of N_2 excretion from total N_2 excretion from animals according to IPCC guidelines using tables B-3, B-4, B-6. Default values for percentage of manure N produced in different animal waste management systems is taken from table 4.21 (IPCC) for dairy cattle, non-dairy cattle, pigs and poultry as follows (see Table 3).

Step 4: N_2O emission per animal is determined by multiplying the nitrogen excretion (N_2 -AWMS) using emission factors (EF_3) according to table 4.22 (IPCC).

IPCC default emission factor for Asia is N_2O – N/kg nitrogen excreted; Anaerobic lagoons and liquid systems = 0.001; Others systems = 0.005.

Step 5: Total emission is determined by multiplying the number of animals in each category with the emission factor. Emissions from all categories are aggregated and total emission expressed as Gg nitrous oxide/yr.

$$\text{Emissions (Gg/yr)} = EF \text{ (kg/head/yr)} \times \text{population} / 10^6 \text{ kg/Gg.}$$

The emission factors based on weighted average for the country as a whole are presented in Table 4.

Discussion

Need for country-specific emission factors

Country-specific methane emission factors were first developed in 1992 for the agriculture sector and improved further during the Asian Least Cost Green House Gas project in a comprehensive effort to update the data^{13,17}. These emission coefficients were developed for different age groups of ruminants, as they are the key source category. However, these emission factors were not region or condition-specific, and possessed inherent uncertainties associated with the activity data. Hence, the present efforts

in India are not only limited to additional measurements, but also to reduce uncertainties in the activity data for proper application in derivation of emission coefficients. Though the task is complex, keeping in view the 'key source category' emission coefficients have been developed for ruminant animals using IFS for estimating feed intake in terms of GE, which is more country-specific.

In this connection it is stated that the Indian cattle have a different genetic make-up compared to the ones reared in developed countries. They are smaller in size with lower body weight, are low in production and adapted to the different climatic conditions and poor feeding situations besides their different heritage. The nutrient requirements for Indian dairy cattle and buffaloes vary from Western standards as the type of animals, feeding and animal husbandry practices are altogether different in the tropical countries. It has been proved experimentally that the metabolism of tropical ruminants is quite different with respect to the lower basal metabolic rates of crossbred cattle. Furthermore, farmers in India by and large feed their cattle and buffalo on crop residues, grazing and by-product concentrates, which are different from Western countries^{6,28}. Therefore, it is necessary to develop emission factors, which are country-specific and conform to IPCC good practice guidance^{23,24}.

IFS for GE estimation

In the Indian context, the feeding standards are more appropriate and country-specific to arrive at GE requirements of ruminants under different feeding situation. The notable feeding standards of India are Morrison standard (1953), Sen, Ray and Ranjhan (1978) and Ranjhan (1990, 1998)^{6,28}. These feeding standards are different from NRC requirements of NAS, USA. The feeding standards pioneered by Ranjhan have been recommended by ICAR through its publication³¹, which gives requirements for all domestic animals recommended by the ICAR for Indian cattle, buffaloes and other livestock. Accordingly, the rations are worked out by the TDN and ME values, which are considered as a guide to good feeding practice in cattle and buffaloes in Asia. The Ranjhan standards, widely recommended by ICAR, are the most authoritative and highly valued for Indian livestock.

The emission factors based on IFS for feed intake estimation are more realistic as:

- (i) They are country-specific and accurate estimation of GE and methane emission is possible, as the energy calculations are based on scientific studies related to nutrition of tropical animals and compare well with IPCC energy equations.
- (ii) GE intake estimation is independent of GE value of feeds and more accurate estimation of methane from dairy cattle is possible by giving proper weightage to milk production.

Table 3. Default values from IPCC table

Type of animal	Anaerobic lagoon	Liquid system	Other systems
Non-dairy cattle	0	0	0
Dairy cattle	6	4	0
Poultry	1	2	52
Pigs	1	38	0

Table 4. Statewise details of methane emission factors adopted for manure management (kg/animal/yr)

State	Annual mean temperature (°C)	Classification	Tier-II approach			Tier-I approach					
			Cattle			Sheep	Goat	Horses and Ponies	Donkeys	Camels	Pigs
			Dairy	Non-dairy	Buffalo						
Andhra Pradesh	27.9	Warm	3.50	2.00	4.15	0.21	0.22	2.18	1.19	2.56	6
Arunachal Pradesh	18.7	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Assam	23.9	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Bihar	25.0	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Goa	27.3	Warm	3.50	2.00	4.15	0.21	0.22	2.18	1.19	2.56	6
Gujarat	26.8	Warm	3.50	2.00	4.15	0.21	0.22	2.18	1.19	2.56	6
Haryana	24.5	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Himachal Pradesh	16.5	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Jammu and Kashmir	12.7	Cool	3.00	1.70	3.80	0.10	0.11	1.09	0.60	1.28	3
Karnataka	25.0	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Kerala	27.3	Warm	3.50	2.00	4.15	0.21	0.22	2.18	1.19	2.56	6
Madhya Pradesh	25.0	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Maharashtra	26.4	Warm	3.50	2.00	4.15	0.21	0.22	2.18	1.19	2.56	6
Manipur	20.4	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Meghalaya	18.6	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Mizoram	20.6	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Nagaland	17.9	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Orissa	26.6	Warm	3.50	2.00	4.15	0.21	0.22	2.18	1.19	2.56	6
Punjab	23.7	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Rajasthan	25.0	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Sikkim	15.0	Cool	3.00	1.70	3.80	0.10	0.11	1.09	0.60	1.28	3
Tamil Nadu	26.6	Warm	3.50	2.00	4.15	0.21	0.22	2.18	1.19	2.56	6
Tripura	24.9	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Uttar Pradesh	23.6	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
West Bengal	25.0	Temperate	3.25	1.85	3.90	0.16	0.17	1.64	0.90	1.92	4
Union Territories	26.2	Warm	3.50	2.00	4.15	0.21	0.22	2.18	1.19	2.56	6
All India			3.30	1.90	4.00	0.18	0.18	1.60	0.96	1.96	4.37

(iii) No bias is attached in the calculation of energy needs (GE values), unlike the DMI method (dry matter intake as % body weight) wherein it is possible to manipulate the energy values using the discretion of the inventor. Furthermore, the values are likely to fluctuate in DMI method due to wide variation in GE values of feeds from different regions of India (14 to 20 MJ/kg feed).

MEF and their comparison

Separate emission factors are worked out for 'desi' and 'crossbred' cattle under dairy (milk and dry) and non-dairy (breeding, work, breeding and work, young stock, others). Due weightage has been given to the production of milk while calculating GE requirement of dairy animals. As the percentage of sub-categories, average body weight and milk data vary from state to state, emission factors also vary. Weighted average of different sub-categories has been taken into consideration while arriving at the emission factor of non-dairy bovines. The fact that young animals below 3 months do not produce methane has

been taken into consideration in our calculations. The MEFs are presented in Tables 4–6.

It is observed that the emission factors are lower than the IPCC default and IPCC Tier-II emission factors. However, compared to ALGAS the emission factors are higher. The variation in emission factors in IFS and ALGAS is due to uncertainty factors in ALGAS in activity data, feed value and methane conversion factors, though both methodologies are region-specific. The emission factors suggested by Singh^{21,22} are almost comparable with the present values.

Inventory based on present estimation

The emission details have been worked out separately for the states for 1997, the year for which latest census data are available. Details of GHG emissions from emission factors and manure management are presented in Tables 7 and 8, and Figure 1. GHG emissions are also presented separately for methane and nitrous oxide along with CO₂ equivalent in Table 9. Among the anthropogenic GHG emission from the animal sector, methane was the highest

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Table 5. Comparison of methane emission factors by different approaches

Category	Methane								Nitrous oxide CLRI IPCC Tier-II
	Enteric fermentation				Manure management				
	IPCC Tier-II	IPCC default	IPCC energy	ALGAS	IPCC Tier-II	IPCC default	IPCC energy	ALGAS	
	CLRI (IFS)	values	equation (NPL)		CLRI (IFS)	values	equation (NPL)		
Cattle									
Indigenous									
Dairy	20–33	46	28	23	3.00–3.50	5.30	3.61	5.30	0.0006
Non-dairy	18–23	25	31	16	1.70–2.00	2.00	3.00	2.00	0.0004
Crossbred									
Dairy	27–52	46	49	32	3.00–3.50	5.30	4.38	5.30	0.0006
Non-dairy	16–28	25	27	15	1.70–2.00	2.00	2.00	2.00	0.0004
Buffalo									
Dairy	27–49	55	42	32	3.80–4.15	4.70	4.82	4.70	
Non-dairy	18–35	55	27	17	3.80–4.15	4.70	3.00	4.70	
Sheep	1.5–5.0	5	5	5	0.10–0.21	0.18	0.18	0.18	
Goat	1.5–5.0	5	5	5	0.11–0.22	0.18	0.18	0.18	
Horses and Ponies	18.0	18	18	18	1.09–2.18	1.60	1.60	1.60	
Donkeys	10.0	10	10	10	0.60–1.19	0.97	0.97	0.97	
Camels	46.0	46	46	46	1.28–2.56	1.96	1.96	1.96	
Pigs	1.0	1	1	1	3.00–6.00	4.50	4.50	4.50	0.0074
Poultry									0.0025

Table 6. Tier-II approach using IFS: Statewise details of MEFs adopted for enteric fermentation – 1997 (kg methane/animal/yr)

State	Cattle							
	Indigenous		Crossbred		Buffalo		Sheep	Goat
	Dairy	Non-dairy	Dairy	Non-dairy	Dairy	Non-dairy		
Andhra Pradesh	24	22	46	21	36	20	5.0	3.5
Arunachal Pradesh	23	21	50	27	27	29	3.0	1.5
Assam	23	20	37	19	34	27	1.5	2.0
Bihar	23	23	38	27	34	27	3.0	3.0
Goa	20	22	32	17	40	26	0.0	4.0
Gujarat	28	22	51	21	41	20	4.0	4.0
Haryana	33	19	45	21	49	22	4.5	5.0
Himachal Pradesh	24	22	36	23	38	20	4.0	3.0
Jammu and Kashmir	24	20	40	26	37	23	3.5	2.5
Karnataka	24	21	42	22	34	22	4.5	3.5
Kerala	25	16	41	16	40	29	4.0	3.5
Madhya Pradesh	23	22	42	21	37	29	4.0	3.5
Maharashtra	23	22	44	20	38	21	5.0	4.0
Manipur	23	23	42	24	39	29	2.5	2.0
Meghalaya	22	19	52	22	32	30	2.0	1.5
Mizoram	22	21	49	16	27	27	0.0	2.0
Nagaland	25	21	48	30	40	34	0.0	1.5
Orissa	21	22	35	21	31	32	3.0	3.5
Punjab	30	21	49	22	49	20	5.0	5.0
Rajasthan	26	19	41	22	40	18	4.0	4.0
Sikkim	20	18	27	25	0	29	3.5	2.0
Tamil Nadu	27	20	40	22	40	21	4.0	4.0
Tripura	20	20	27	19	27	29	2.0	1.5
Uttar Pradesh	25	21	40	28	39	23	4.5	3.5
West Bengal	25	20	43	19	45	35	2.5	3.0
Union Territories	26	21	42	26	49	25	4.5	3.0
All India	25	21	43	23	40	23	4.0	3.5

Table 7. GHG emission from different sources – IFS (enteric fermentation, manure management and nitrous oxide) – 1997

Category	No. in thousands	Methane emission (Gg/yr)			% Contribution	Nitrous oxide (Gg/yr)
		Enteric fermentation	Manure management	Total		
Cattle	198881	4583.4	459.5			
Indigenous	178782	3954.0	409.6	4363.60	48.32	0.0815
Dairy	49874	1246.9	164.6	1411.50	15.63	0.0299
Non-dairy	128908	2707.1	245.0	2952.10	32.69	0.0516
Below 1 year	25671	539.1	48.8	587.90	6.51	
1–3 years	32041	672.9	60.9	733.80	8.13	
Others*	71196	1495.1	135.3	1630.40	18.06	
Crossbred	20099	629.4	49.9	679.30	7.52	0.0097
Dairy	8356	359.3	27.6	386.90	4.28	0.0050
Non-dairy	11743	270.1	22.3	292.40	3.24	0.0047
Below 1 year	4429	101.9	8.4	110.30	1.22	
1–3 years	3599	82.8	6.8	89.60	0.99	
Others*	3715	85.4	7.1	92.50	1.02	
Buffalo	89918	279.4	359.6	3154.00	34.93	
Dairy	42732	1709.3	170.9	1880.20	20.82	
Non-dairy	47186	1085.1	188.7	1273.80	14.11	
Below 1 year	19418	446.5	77.7	524.20	5.81	
1–3 years	15784	363.0	63.1	426.10	4.72	
Others*	11984	275.6	47.9	323.50	3.58	
Sheep	57494	230.0	10.3	240.30	2.66	
Goat	122721	429.5	22.1	451.60	5.00	
Horses and Ponies	827	14.9	1.3	16.20	0.18	
Donkeys	882	8.8	0.8	9.60	0.11	
Camels	912	42.0	1.8	43.80	0.49	
Pigs	13291	13.3	58.1	71.40	0.79	0.0984
Poultry	324027	0.0	0.0	0.00	0.00	0.8101
Total	484926	8116.3	913.5	9029.80	100.00	

*Includes adult males (working, breeding and both) and non-dairy adult females.

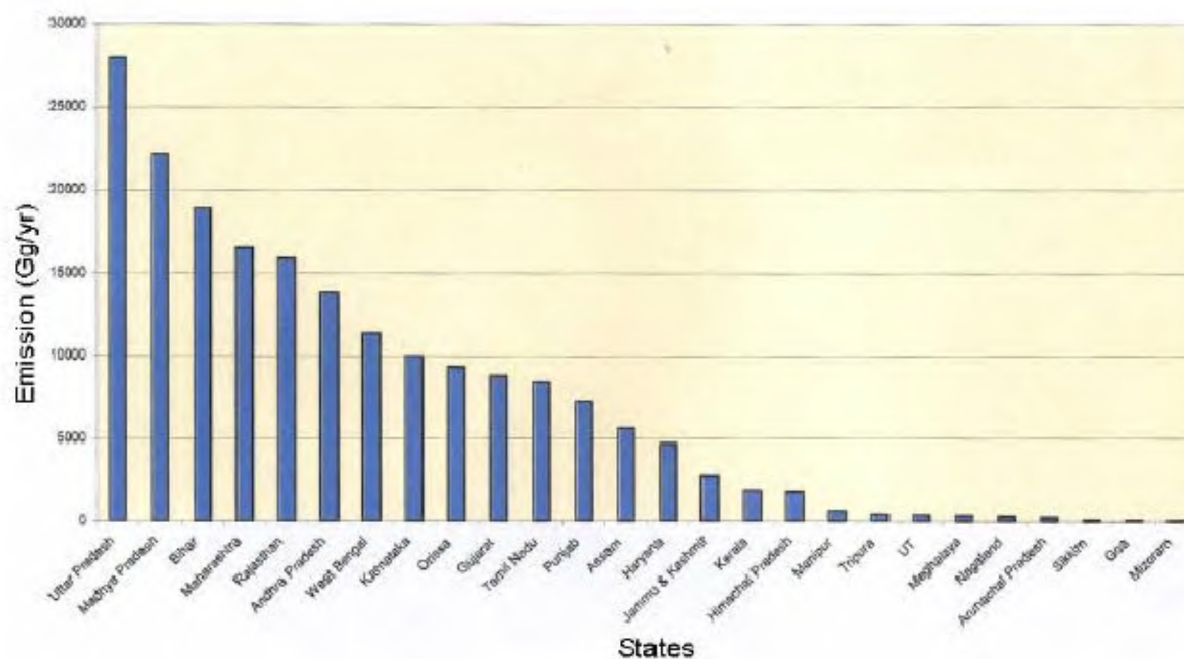
**Figure 1.** GHG emission from states.

Table 8. Comparison of GHG emission by different approaches

Category	Methane								Nitrous oxide CLRI IPCC Tier-II
	Enteric fermentation				Manure management				
	CLRI	IPCC default values	IPCC Tier-II energy equation (NPL)	ALGAS	CLRI	IPCC default values	IPCC Tier-II energy equation (NPL)	ALGAS	
Cattle									
Indigenous									
Dairy	1246.9	2294.2	1396.5	1147.1	164.6	264.3	180.0	264.3	0.0299
Non-dairy	2707.1	3222.7	3996.1	2062.5	244.9	257.8	386.7	257.8	0.0516
Crossbred									
Dairy	359.3	384.4	409.4	267.4	27.6	44.3	36.6	44.3	0.0050
Non-dairy	270.1	293.6	317.1	176.1	22.3	23.5	23.5	23.5	0.0047
Buffalo									
Dairy	1709.3	2350.3	1794.7	1367.4	170.9	200.8	206.0	200.8	
Non-dairy	1085.3	2595.2	1274.0	802.2	188.7	221.8	141.6	221.8	
Sheep	230.0	287.5	287.5	287.5	10.3	10.3	10.3	10.3	
Goat	429.5	613.6	613.6	613.6	22.1	22.1	22.1	22.1	
Horses and Ponies	14.9	14.9	14.9	14.9	1.3	1.3	1.3	1.3	
Donkeys	8.8	8.8	8.8	8.8	0.8	0.9	0.9	0.9	
Camels	42.0	42.0	42.0	42.0	1.8	1.8	1.8	1.8	
Pigs	13.3	13.3	13.3	13.3	58.1	59.8	59.8	59.8	0.0984
Poultry									0.8101
Total	8116.3	12120.4	10167.9	6802.8	913.5	1108.8	1070.6	1108.7	0.9997

	Total emission	
	Methane	Nitrous oxide
CLRI	9029.8	
IPCC default values	13229.2	0.9997
NPL	11238.5	
ALGAS	7911.5	

(99.999%) with N₂O accounting for only a small fraction (0.0001%), which is negligible.

The present inventory with most of the uncertainties removed is a reasonable estimation for the country as a whole, as it is more country-specific compared to other methodologies. The present estimation of methane from domestic animal source (anthropogenic activities) is 9 Tg (range 8 to 10 Tg), of which 8 Tg (90%) is from enteric fermentation and the balance 1 Tg (10%) from manure management. Nitrous oxide is 0.001 Tg. In terms of CO₂ equivalent, the total GHG emission is 190 Tg. As nitrous oxide emission is negligible, it has not been taken into consideration for analyses of major parameters.

The present estimation is 21–32% less when compared to values utilizing IPCC default emission factors and IPCC Tier-II methodologies using IPCC energy equations for calculating GE intake presented in Table 8. However, the GHG emission (methane) values are higher by 14% when compared to previous national inventories (ALGAS). This is due to the fact that the body weights taken in the present inventories with regard to cattle and buffalo are

slightly higher than ALGAS, so also the gross energy value.

The proportional contribution of GHG emission from enteric fermentation and manure management is almost in the ratio of 9 : 1. This ratio is maintained in all the states with marginal variations.

Bulk of the emission is from the bovine population (91%), i.e. cattle (55.8%) and buffalo (35.2%) followed by small ruminants 7.6% (sheep 2.6% and goat 5.0%) and a small/negligible emission from the remaining animal population (1.4% from camels, horses and ponies, donkeys and pigs).

The proportional contribution of cattle, buffalo, small ruminants and others is 56.4, 34.4, 8.1 (sheep 2.8 and goat 5.3%) and 1.1% respectively, in enteric fermentation and cattle 50.3%, buffalo 39.3%, small ruminants 3.5% (sheep 1.1% and goat 2.4%) and others 6.9% with respect to manure management.

Quantitative analysis of the data reveals that the northern region contributed highest methane (33%) followed by eastern (24%), western (25%) and southern regions (18%).

Table 9. Statewise/regionwise details of GHG emission

State	Methane				Nitrous oxide		Total carbon dioxide equivalent	% Contri- bution	Density (GHG)	
	Enteric fermentation (Gg/yr)	Manure management (Gg/yr)	Total (Gg/yr)	Carbon dioxide equivalent	Nitrous oxide	Carbon dioxide equivalent			Area (sq. km)	Gg/kg km/yr
Northern										
Haryana	240.52	27.78	268.29	5634.17	0.0320	9.92	5644.09	2.97	44212	0.13
Himachal Pradesh	82.98	8.30	91.28	1916.96	0.0028	0.87	1917.83	1.01	55673	0.03
Jammu and Kashmir	120.39	10.39	130.78	2746.38	0.0140	4.34	2750.72	1.45	222236	0.01
Punjab	316.21	31.30	347.51	7297.69	0.0512	15.87	7313.56	3.85	50362	0.15
Rajasthan	709.53	75.20	784.73	16479.23	0.0162	5.02	16484.25	8.68	342239	0.05
Uttar Pradesh	1188.31	143.53	1331.83	27968.47	0.0620	19.22	27987.69	14.74	294411	0.10
Sub total	2657.94	296.49	2954.42	62042.90	0.1782	55.24	62098.15	32.69	1009133	0.06
Eastern										
Arunachal Pradesh	10.78	2.04	12.82	269.28	0.0051	1.58	270.86	0.14	83743	0.00
Assam	197.83	25.58	223.41	4691.53	0.0588	18.23	4709.75	2.48	78438	0.06
Bihar	813.92	83.93	897.85	18854.85	0.0638	19.78	18874.63	9.94	173877	0.11
Manipur	15.66	3.00	18.66	391.94	0.0115	3.57	395.51	0.21	22327	0.02
Meghalaya	16.74	3.21	19.95	418.95	0.0078	2.42	421.37	0.22	22429	0.02
Mizoram	1.13	0.74	1.87	39.35	0.0042	1.30	40.66	0.02	21081	0.00
Nagaland	12.62	3.25	15.88	333.38	0.0113	3.50	336.88	0.18	16579	0.02
Orissa	374.42	44.22	418.64	8791.38	0.0439	13.61	8804.99	4.64	155707	0.06
Sikkim	3.41	0.41	3.82	80.22	0.0011	0.34	80.56	0.04	7096	0.01
Tripura	26.49	3.85	30.34	637.12	0.0095	2.95	640.06	0.34	10486	0.06
West Bengal	487.93	51.16	539.09	11320.79	0.0952	29.51	11350.30	5.98	88752	0.13
Sub total	1960.93	221.40	2182.32	45828.78	0.3122	96.78	45925.57	24.18	680515	0.07
Western										
Goa	3.35	1.00	4.35	91.37	0.0028	0.87	92.24	0.05	3702	0.02
Gujarat	398.41	45.86	444.27	9329.71	0.0189	5.86	9335.57	4.92	196024	0.05
Madhya Pradesh	950.23	102.64	1052.86	22110.14	0.0514	15.93	22126.08	11.65	443446	0.05
Maharashtra	675.71	76.19	751.90	15789.88	0.1015	31.47	15821.34	8.33	307690	0.05
Sub total	2027.70	225.69	2253.39	47321.11	0.1746	54.13	47375.23	24.94	950862	0.05
Southern										
Andhra Pradesh	581.91	73.04	654.95	13753.95	0.1475	45.73	13799.68	7.27	275068	0.05
Karnataka	430.71	46.03	476.75	10011.67	0.0490	15.19	10026.86	5.28	191791	0.05
Kerala	79.37	8.20	87.57	1839.05	0.0611	18.94	1858.00	0.98	38863	0.05
Tamil Nadu	358.58	40.36	398.93	8377.61	0.0734	22.75	8400.37	4.42	130058	0.06
Sub total	1450.57	167.63	1618.20	33982.28	0.3310	102.61	34084.89	17.95	635780	0.05
Union Territories										
UT	19.19	2.34	21.53	452.13	0.0037	1.15	453.28	0.24	10973	0.04
Total	8116.32	913.55	9029.87	189627.21	0.9997	309.91	189937.11	100.00	3287263	0.06

The top three GHG emitting states (CO₂ equivalent) in descending order are: Uttar Pradesh (27,988 Gg), Madhya Pradesh (22,126 Gg) and Bihar (18,875 Gg). Mizoram (41 Gg), Sikkim (81 Gg) and Goa (92 Gg) are at the bottom of the list.

Hotspots

Uttar Pradesh and Madhya Pradesh together contribute more than 25% of the total emission and the top five states (Uttar Pradesh, Madhya Pradesh, Bihar, Rajasthan and Maharashtra) accounted for more than 50% of the

country's emission (53%). The hotspots are Uttar Pradesh, Madhya Pradesh and Bihar while Mizoram, Sikkim, Goa are the green spots as far as total emissions are concerned.

The top three states contributing highest methane from enteric fermentation are Uttar Pradesh, Madhya Pradesh and Bihar. Mizoram, Goa and Sikkim are again at the bottom of the list.

Density

The density of GHG emission (CO₂ equivalent) varied from state to state and there was wide variation ranging from

0.15 Gg/sq. km in Punjab/West Bengal to 0.0001 Gg sq. km in Arunachal Pradesh/Mizoram – with the (all-India) average being 0.06 Gg sq. km (Figure 2).

Region-wise analysis revealed that the eastern region topped the list (0.07 Gg/sq. km) followed by the northern (0.06 Gg/sq. km), southern (0.05 Gg/sq. km), and western regions (0.05 Gg/sq. km) and Union Territories (UTs) being 0.04 Gg/sq. km. The reason for increased density from the eastern region is due to higher bovine population and higher emissions from Bihar and West Bengal. However, if the northeastern zone is considered as a separate entity, it is only 0.03 Gg/sq. km (northeast). If the northeastern zone is excluded, the average works out to 0.09 Gg/sq. km (highest density) in the eastern states consisting of West Bengal, Orissa and Bihar.

Methane emission

Dairy vs non-dairy sector: Among bovines, non-dairy cattle are the highest (35.9%) followed by dairy buffalo (20.8%), dairy cattle (19.9%) and non-dairy buffalo (14.1%). The non-dairy sector contributed more methane in cattle while the dairy sector was the highest in buffalo (Figure 3).

Milk yield vs methane: The all-India average for methane production per kg of milk is 41, 21 and 31 g/kg respectively, for indigenous cattle, crossbred cattle and buffalo (Figure 4). However, wide regional variations exist, with

Orissa recording more than the highest of 100 g/kg milk while the lowest was in Haryana and Punjab (23–25 g/kg) in case of indigenous cattle. In case of crossbred cattle, the highest was from Goa (51 g/kg) and lowest from Punjab (16 g/kg). In case of buffalos, Orissa, Meghalaya and Assam recorded highest methane emission (57–45 g/kg) and lowest being Punjab, Haryana, West Bengal and UTs (23–29 g/kg).

It is clear from the data that the emission rates are always dependent on productivity of the animal, i.e. higher the milk production higher the emission factor. Another significant feature is the rate of methane production per unit of milk produced. Methane emission per kg milk was always lower in high milk-yielding animals. Furthermore, despite higher body weights of crossbred cattle/buffalo, methane/kg milk was always low compared to indigenous cattle.

Emission factors in general are in the order of: Crossbred cattle (43) > buffalo (40) > indigenous cattle (25), whereas methane/unit of milk is in the order of: Indigenous cattle (41) > buffalo (31) > crossbred cattle (21).

Based on methane emission in relation to milk production a correlation could be established as follows: Higher the milk yield, higher is CH₄/kg body weight and lower is CH₄/kg milk. Lower the milk yield, lower is CH₄/kg body weight and higher is CH₄/kg milk.

This study also indicates the present state of dairy animals in different states. In other words, the productivity and nutritional status of dairy animals can be visualized by glancing through the comparative methane production per unit milk: Higher the methane/kg milk, lower the milk yield/per animal with nutritional status not good. Lesser the methane/kg milk, higher is the milk yield/per animal with better nutritional status.

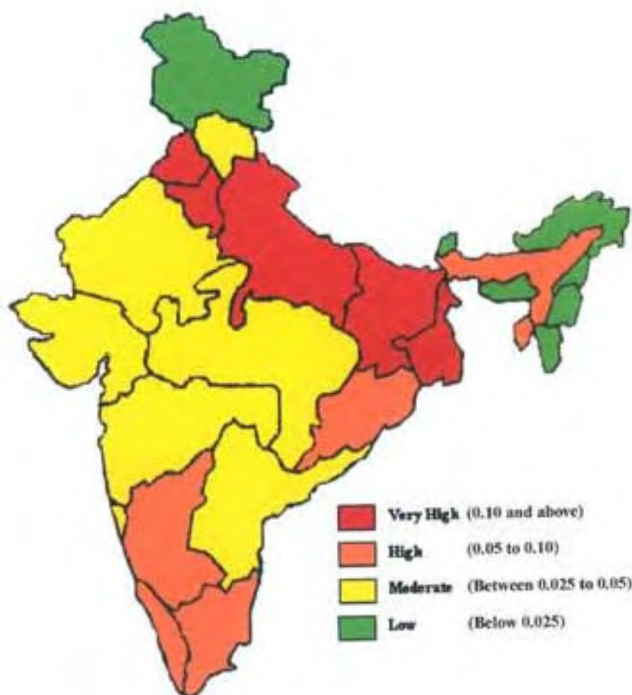


Figure 2. Distribution of methane density (Gg/sq. km/yr).

Abatement strategy: At both community and international levels, it has been recognized that methane reduction policy should be an important element of the overall climate change strategy, especially in view of the fact that implementation of methane reduction strategy could have a more immediate impact compared to measures adopted for CO₂. In the agricultural sector, the most promising area for reducing methane emission is from livestock and more particularly bovine animals. There has been a growing awareness among the researchers in India for improved nutrition of large ruminants fed on crop residues, agro-industrial by-products or tropical pastures and for implementing/proposing feeding strategies for ecofriendly animal production in India, which also reduces methane production^{32–34}. The abatement strategy for methane in the Indian context with reference to livestock needs to be cost-effective. It should also address religious and socio-economic problems. Therefore, a set of potential effective abatement strategies is needed. The potential options for mitigation strategy are as follows.

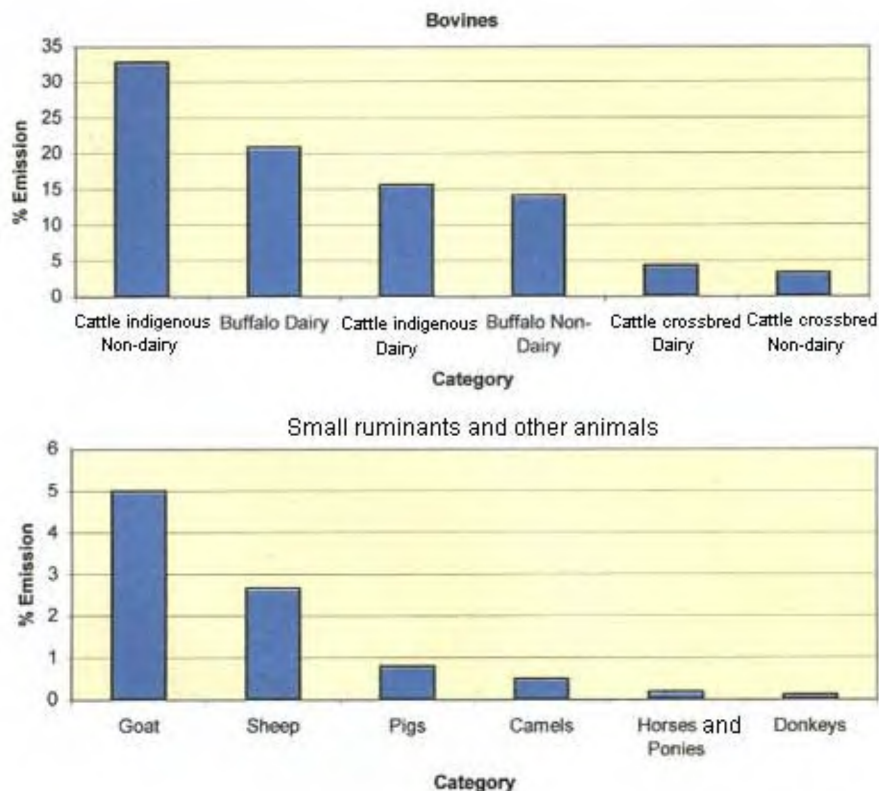


Figure 3. Per cent contribution of methane by different categories of livestock (enteric fermentation and manure management).

Livestock reduction: In the Indian context, it is a difficult option due to religious and socio-economic conditions as majority of the farmers are dependent on livestock for agricultural work besides the religious sentiments attached to cattle. Nevertheless, introduction of improved breeds with higher productivity/efficiency can bring about a gradual change. Comparison of population data of 1992 and 1997 has indicated increase in the number of higher breeds and reduction in less productive indigenous cattle. This has resulted in considerable reduction in cattle population.

Increase of feed conversion efficiency: It is possible to reduce energy losses through methanogenesis and to improve animal efficiency by: (a) Replacement of roughages with concentrates and a change in composition of concentrates. (b) Modification in feeding like alkali/ammonia treatment of low digestibility straws. (c) Supplementation with molasses, urea nutrient blocks. (d) Defaunation through mineral/protein supplementation.

If the modified feed intake results in less acetate and more propionate from rumen fermentation, it results in the productivity of the animals as well as reduction of methane.

Increase in animal productivity: By adding production-enhancing agents to animal feeds, animal productivity

(milk/beef) can be improved. Many antibiotics, ionophors and halogenated compounds are known for production stimulation and some of them have a direct effect on methanogenesis in the rumen. This may not be practical in the Indian context.

Animal productivity can also be improved through transgenic manipulation or biotechnology reproduction techniques.

Manure management: (a) Better manure management and methane recovery techniques. The recovered methane can be used for energy generation/flaring. The flaring process decreases up to 95% of harmful atmospheric effect of methane. (b) To create a condition unfavourable for methane generation. If livestock manure is kept under aerobic condition by turning the manure regularly, methane emission from manure management can be reduced.

Uncertainty reduction and future needs

Uncertainties can only be reduced and can never be eliminated altogether. Though considerable efforts have been made in the present work to reduce uncertainties in the activity data, uncertainties continue to remain as the available emission measurements are confined to a few bovine stock of northern India. Furthermore, uncertainties

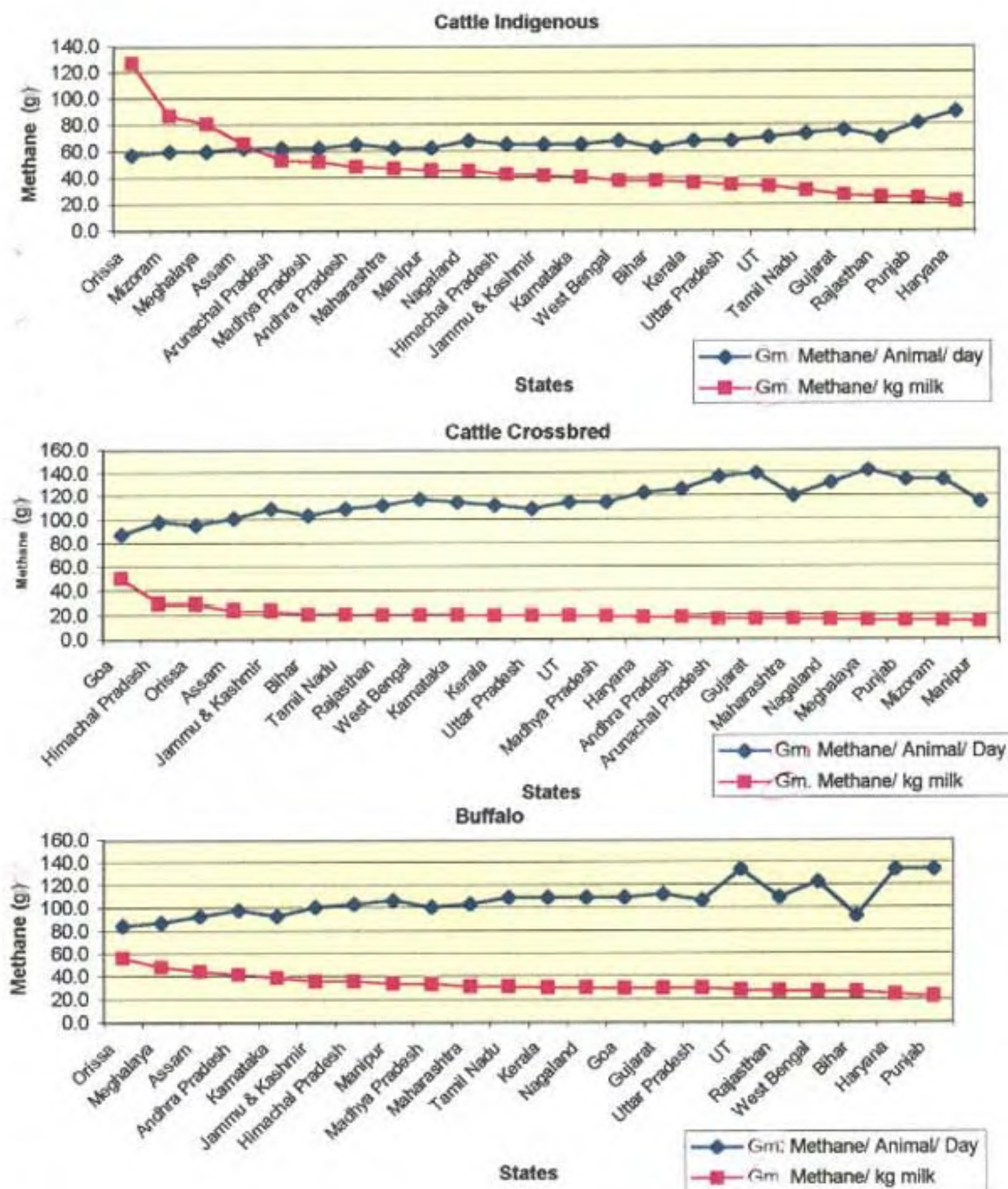


Figure 4. Milk production vs methane emission.

also continue to exist in the body weights and feed intake of cattle and buffalo as well as GE values of Indian feeds. Therefore, the following studies are needed.

1. Laboratory and field-level studies on methane emissions (enteric fermentation and manure management) from cattle, buffaloes, goat and sheep (of different age groups at different production levels) at state/regional level.
2. National level survey/study to estimate body weight, feed intake (actual) by bovines in all the states/UTs.
3. Determination of GE value of all the Indian feeds by an appropriate method like bomb calorimetry.

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