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Methane emissions of cows under different livestock farming systems in Nagpur

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Abstract

Methane is a globally emerging threat as green house gases and cows are considered the great methane emitter. However, emission shall be studied class wise to put more emphasis on particular class for mitigation process. The present study estimated the enteric methane emissions of the cows under different livestock farming systems in the Nagpur from June 2025 to January, 2026 using IPCC 2019 Tier-1, Tier-2 (GE) and Tier-2 (DMI) methodologies. The livestock farming systems (LFS) was categorized as small (<20), medium (20-50) and large (50<). The population of the cow and milk production status data was collected. The methane emission from lactating cows was 916.04 ± 47.01 kg CH₄ yr⁻¹ and from non-lactating cows was 432.89 ± 26.72 kg CH₄ yr⁻¹ by Tier-1 methodology. Using IPCC Tier-2 (GE) method, the overall methane emission of lactating cow was 1712.28 ± 89.25 kg CH₄ yr⁻¹ and from non-lactating cows was 646.78 ± 39.52 kg CH₄ yr⁻¹. The pooled mean methane emission from lactating and non-lactating cows was 1905.25 ± 101.93 kg CH₄ yr⁻¹ and 550.65 ± 33.96 kg CH₄ yr⁻¹, respectively using Tier-2 (DMI) method. The total methane emissions from all cows was estimated at 688.84 ± 25.98 , 1280.15 ± 28.10 and 2497.27 ± 99.46 kg CH₄ yr⁻¹ for Tier-1, 1187.80 ± 46.63 kg CH₄ yr⁻¹, 2239.71 ± 46.89 kg CH₄ yr⁻¹, and 4389.09 ± 162.56 kg CH₄ yr⁻¹ for Tier-2 (GE) and 1234.74 ± 49.65 , 2311.61 ± 52.15 and 4628.60 ± 172.20 kg CH₄ yr⁻¹ for Tier-2 (DMI) in small, medium, and large livestock farming systems. LFS differ in methane emission and increase in cow population increases methane emission. Lactating cow emits more methane as compared to non-lactating, for both tyre I and tyre II methods, suggests that more judicious interventions shall be employed on lactating cow for methane mitigation process. The unit methane production was more in large LFS suggest that methane reduction strategies required in large LFS as compared to Small and Medium.

Keywords: Methane emission, IPCC methodology, cows, livestock farming systems, Nagpur

Introduction

The livestock sector forms the backbone of rural livelihoods and significantly contributes to the agricultural economy in India. Ruminants are recognized as the primary contributors to methane emissions globally. India possesses the largest populations of buffalo and goats and ranks second in cattle and sheep populations worldwide (FAOSTAT, 2023) [7]. Methane is produced during the digestive process of ruminant animals such as cattle as a natural by-product of enteric fermentation. As a potent greenhouse gas, methane (CH₄) plays a critical role in atmospheric processes and climate change. Its global warming potential is approximately 28 times higher than that of carbon dioxide (CO₂) (IPCC, 2022; MoEFCC, 2021) [13, 18]. Due to its vast livestock population, India is a major contributor of methane emissions arising from enteric fermentation and manure handling. Additionally, methane contributes to global warming and acts as a precursor in the formation of tropospheric ozone (Francoeur *et al.*, 2021; Manahan, 2017) [8, 17].

In ruminant animals, nearly 95% of methane is released through the mouth and nostrils, with the remaining 5% emitted through the anal canal. Methane is formed during the anaerobic digestion of cellulose and other feed components by methanogenic bacteria, which use hydrogen (H₂) produced in the rumen. The amount of methane produced depends on the nature of fermentable carbohydrates and the balance between propionic and acetic acid production (Lassey, 2017; Jha *et al.*, 2011) [16, 14]. Methane formation results in a loss of energy that could otherwise support animal productivity.

This process is known as “enteric fermentation.” In addition, methane emissions also arise from manure management systems in livestock farming

Various studies have estimated greenhouse gas emissions from India's livestock sector using different methodologies (Chhabra *et al.*, 2009; Patra, 2012; Singhal *et al.*, 2005; Swamy and Bhattacharya, 2006) [2, 20, 21, 22]. Globally, livestock contributes 14.5% of GHG emissions, with 40% attributed to enteric methane from cattle (Tee *et al.*, 2022) [23]. India's National GHG Inventory indicates that enteric fermentation produces around 130-140 million metric tons of CO₂-equivalent methane annually. In 2020, emissions were estimated at 222,632 Gg CO₂e, a slight decline of 0.28% compared to 2019 (Department of Animal Husbandry and Dairying, 2014; 2019) [4, 5]. According to the IPCC (2022) [13], India is one of the largest emitters of methane due to its substantial cattle and buffalo populations. Livestock contributes about 48% of national methane emissions, followed by the waste sector (20%) and rice cultivation (15%) (GHG Platform India, 2022) [10].

Enteric methane emissions are largely influenced by livestock population size, with higher animal numbers leading to increased emissions. Additional factors such as diet, topography, energy intake, and body weight also affect methane production. Hence the present study was undertaken to estimate the methane emissions of cows in different livestock farming systems in Nagpur.

Materials and Methods

Location of the study area: The present study was conducted on the different livestock farming systems in different tehsils of Nagpur district, Maharashtra.

Collection of data: The study utilized both traditional survey methods and direct field observations to collect data from the livestock farming systems. A comprehensive interview schedule was developed based on the study objectives to gather information on the general profile of the LFS including, size, daily milk yield, livestock population, and prevailing management practices.

Estimation of methane emission using IPCC methodology: As per the Intergovernmental Panel for Climate Change (IPCC, 2006) [11] guidelines, methane emissions from cattle arising from enteric fermentation can be estimated using two standardized approaches, known as the Tier-1 and Tier-2 methodology.

Tier-1 method: The Tier-1 method is considered the simplest and most widely adopted approach for estimating methane emissions. It uses default emission factors developed by the IPCC (2006) [11] for different livestock categories. In IPCC Tier-1 methodology, country-wise livestock category-wise specific emission factors are available.

Enteric fermentation emissions from a livestock category

$$E_T = \sum_{(P)} EF_{(T,P)} \cdot \left(\frac{N_{(T,P)}}{10^6} \right) \times \text{Gg/CH}_4 \text{ yr}^{-1}$$

E_T = methane emissions from Enteric Fermentation in animal category T, Gg CH₄ yr⁻¹

$EF_{(T,P)}$ = emission factor for the defined livestock population T and the productivity system P, in kg CH₄ head⁻¹ yr⁻¹

$N_{(T,P)}$ = the number of head of livestock species/category T in the country classified as productivity system P

T = species/category of livestock

P = productivity system, either high or low productivity for use in advanced Tier-1.

Emission of methane based on Tier-1 system: There are three steps for the calculation of Tier-1 system: Step-1: Categorization and estimation of cattle population. Step-2: Emission factor collection from IPCC guidelines. IPCC-2019 provide emission factors for both average emission factor. Then we compared the calculation obtained from considering both emission factor. Step-3: Estimation of total methane emission by multiplying cattle population with emission factors.

Tier-2 Method

The Tier-2 approach is an enhanced approach that necessitates knowledge of animal categories, production and feeding methods, and manure management. Feed intake data for a representative animal in each class are needed for Tier-2 method. Typically, feed intake is expressed as dry matter (e.g., kilograms (kg) or gross energy (e.g., mega joules (MJ)) ingested daily. According to Eggelosten *et al.* (2019), the Tier-2 approach consists of three steps.

Steps 1: Data on the livestock population (including animal population and associated activity data) were obtained.

Steps 2: The methane conversion factor and dry matter intake for each animal group was used to estimate the emission factors. According to the Tier-2 approach, the emission factor must be determined by completing the subsequent sub-steps.

Step 3: To estimate total emissions, the selected emission factors was multiplied by the associated animal population and summed. As described above under Tier-1, the emissions estimates were reported in gigagrams (Gg).

Calculation of methane emission based on dry matter intake:

$$\text{Emission Factor (EF)} = \text{DMI} \times \left(\frac{\text{MY}}{1000} \right) \cdot 365$$

Here, EF = Emission Factor, kg CH₄ head⁻¹ yr⁻¹

DMI = kg DMI per day

MY = Methane yield, kg CH₄ DMI⁻¹

365 = days per year

1000 = conversion from g CH₄ to kg CH₄

Then, DMI for lactating dairy cows,

$$\text{DMI} = 0.0185 \cdot \text{BW} + 0.305 \cdot \text{FCM}$$

Where,

DMI = dry matter intake, kg day⁻¹

BW = live body weight, kg

FCM = Fat corrected milk, kd day⁻¹, 3.5 percent * [(0.4324 * kg of milk) + (16.216 * kg of fat)]

Calculation of methane emission based on Gross energy:

$$EF = \frac{GE \cdot \left(\frac{YM}{100} \right) \cdot 365}{55.65}$$

EF = Emission Factor, kg CH₄ head⁻¹ yr⁻¹

GE = Gross energy intake, MJ head⁻¹ yr⁻¹

Y_m = Methane conversion factor, percent of gross energy in feed converted to methane

The factor 55.65 (MJ/kg CH₄) is the energy content of methane

Gross energy (GE)

GE requirement is derived based on the summed net energy requirements and the energy availability characteristics of the feed(s).

$$GE = \left[\frac{(NEm + NEa + NEl + NEwork + NEp)}{REM} + \frac{(NEg)}{REG} \right] \times DE$$

GE = Gross energy, MJ day⁻¹

NE_m = net energy required by the animal for maintenance, MJ day⁻¹

NE_a = net energy for animal activity, MJ day⁻¹

NE_l = net energy for lactation, MJ, day⁻¹

NE_{work} = net energy for work, MJ, day⁻¹

NE_p = net energy required for pregnancy, MJ day⁻¹

REM = ratio of net energy available in a diet for maintenance to digestible energy

NE_g = net energy needed for growth, MJ day⁻¹

REG = ratio of net energy available for growth in a diet to digestible energy consumed

DE = digestibility of feed expressed as a fraction of gross energy (digestible energy/gross energy), i.e. DE%/100

Emission of methane based on Tier-2 system (2019)

Step-1 (Methane yield development): Here, methane yield is provided by IPCC-2019 for different cattle categories and sub categories.

Step-2 (Emission factor development): For the development of emission factor, DMI value is required. Again, to estimate DMI the data of body weight followed by estimated dietary net energy concentration of the feed or diet (NE_{mf}) is needed.

Step-3 (Total emission calculation): Total emission was calculated by multiplying the number of cattle with emission factor.

Results

Methane emissions by cows at different livestock farming system using IPCC Tier-1 method

The mean methane emissions estimated by Tier-1 method for lactating cows were recorded as 461.077±20.249 kg CH₄ yr⁻¹ in small LFS, 869.137±20.297 kg CH₄ yr⁻¹ in medium LFS and 1706.111±75.910 kg CH₄ yr⁻¹ in large LFS. The pooled average of methane emissions from lactating cows was 916.042±47.011 kg CH₄ yr⁻¹. The mean enteric methane emissions from non-lactating cows were estimated using IPCC Tier-1 method at 227.769±20.242 kg CH₄ yr⁻¹ in small LFS, 411.020±21.170 kg CH₄ yr⁻¹ in medium LFS, and 791.167±69.698 kg CH₄ yr⁻¹ in large LFS. The pooled mean methane emission from non-lactating cows was 432.895±26.724 kg CH₄ yr⁻¹. The assessment of enteric methane emissions using IPCC Tier-1 method from total cows revealed mean values of 688.846±25.979 kg CH₄ yr⁻¹ in small LFS, 1280.157±28.103 kg CH₄ yr⁻¹ in medium LFS, and 2497.278±99.467 kg CH₄ yr⁻¹ in large LFS. The overall mean methane emission for total cows in the Nagpur district

from Tier-1 method was estimated at 1348.937±67.420 kg CH₄ yr⁻¹. The findings of the present study differ from those reported by Das *et al.* (2017) [3], who documented enteric methane emissions of 232 kg CH₄ yr⁻¹ in smallholder LFS, 812 kg CH₄ yr⁻¹ in medium LFS, and 8120 kg CH₄ yr⁻¹ in large LFS. The differences might be attributed to average herd size.

Methane emissions by animals at different livestock farming system using IPCC Tier-2 (Gross Energy) method

Using Tier-2 (Gross Energy), the mean methane emissions of lactating cows were 850.004±37.529 kg CH₄ yr⁻¹, 1622.276±40.835 kg CH₄ yr⁻¹ and 3212.840±139.813 kg CH₄ yr⁻¹ in small, medium and large LFS. The overall average methane emission of lactating cows estimated by the Tier-2 (Gross Energy) method across all LFS were 1712.287±89.255 kg CH₄ yr⁻¹. The mean enteric methane emissions from non-lactating cows were recorded as 337.799±29.977 kg CH₄ yr⁻¹ in small LFS, 617.435±30.468 kg CH₄ yr⁻¹ in medium LFS, and 1176.256±104.016 kg CH₄ yr⁻¹ in large LFS. The overall mean methane emission from non-lactating cows in the Nagpur district was 646.785±39.526 kg CH₄ yr⁻¹. The mean values of enteric methane emissions from total cows using IPCC Tier-2 (Gross Energy) method which is 1187.803±46.630 kg CH₄ yr⁻¹ in small LFS, 2239.711±46.893 kg CH₄ yr⁻¹ in medium LFS, and 4389.095±162.563 kg CH₄ yr⁻¹ in large LFS. The overall mean methane emission from total cows in the Nagpur district was 2359.072±118.310 kg CH₄ yr⁻¹. The results of the present study are similar from those studied by Aydin and Koknaroglu (2023) [1], who reported the enteric methane emissions of 856 kg CH₄ yr⁻¹ from smallholder LFS, 1918 kg CH₄ yr⁻¹ from medium LFS, and 3970 kg CH₄ yr⁻¹ from large LFS (converted from CO₂-eq by dividing the values by GWP of 28).

Methane emissions by animals at different livestock farming system using IPCC Tier-2 (Dry Matter Intake) method

As presented in the study, lactating cows in small, medium, and large LFS exhibited mean enteric methane emissions of 949.158±42.955 kg CH₄ yr⁻¹, 1786.288±49.929 kg CH₄ yr⁻¹, and 3623.324±161.287 kg yr⁻¹, respectively using IPCC Tier-2 (Dry Matter Intake) method. The pooled mean methane emission for lactating cows across the Nagpur district was calculated to be 1905.249±101.937 kg CH₄ yr⁻¹. The mean methane emissions from non-lactating cows were recorded as 285.583±25.379 kg CH₄ yr⁻¹ in small LFS, 525.327±26.483 kg CH₄ yr⁻¹ in medium LFS, and 1005.278±89.062 kg yr⁻¹ in large LFS. The combined mean methane emissions from non-lactating cows across all livestock farming systems was 550.651±33.962 kg CH₄ yr⁻¹. The mean values of enteric methane emissions from total cows using IPCC Tier-2 (Dry Matter Intake) method was 1234.741±49.655 kg CH₄ yr⁻¹, 2311.615±52.155 kg CH₄ yr⁻¹ and 4628.602±172.203 kg CH₄ yr⁻¹ in small, medium and large dairy LFS. The overall average of the methane emissions from total cows in small, medium and large livestock farming systems was 2455.900±125.945 kg CH₄ yr⁻¹. The results from Aydin and Koknaroglu (2023) [1] were used to compare outcomes for methane emissions from both Tier-2 (Gross Energy) and Tier-2 (Dry Matter Intake) method.

Table 1: Mean $\pm$ SE values of methane emission under different livestock farming system in Nagpur district (in kg CH₄ yr⁻¹)

Livestock farming system	Tier-1 method			Tier-2 (Gross Energy) method			Tier-2 (Dry Matter Intake) method		
	Lactating cows	Non-lactating cows	Total cows	Lactating cows	Non-lactating cows	Total cows	Lactating cows	Non-lactating cows	Total cows
Small	461.077 $\pm$ 20.249	227.769 $\pm$ 20.242	688.846 $\pm$ 25.979	850.004 $\pm$ 37.529	337.799 $\pm$ 29.977	1187.803 $\pm$ 46.630	949.158 $\pm$ 42.955	285.583 $\pm$ 25.379	1234.741 $\pm$ 49.655
Medium	869.137 $\pm$ 20.297	411.020 $\pm$ 21.170	1280.157 $\pm$ 28.103	1622.276 $\pm$ 40.835	617.435 $\pm$ 30.468	2239.711 $\pm$ 46.893	1786.288 $\pm$ 49.929	525.327 $\pm$ 26.483	2311.615 $\pm$ 52.155
Large	1706.111 $\pm$ 75.910	791.167 $\pm$ 69.698	2497.278 $\pm$ 99.467	3212.840 $\pm$ 139.813	1176.256 $\pm$ 104.016	4389.095 $\pm$ 162.563	3623.324 $\pm$ 161.287	1005.278 $\pm$ 89.062	4628.602 $\pm$ 172.203
Pooled	916.042 $\pm$ 47.011	432.895 $\pm$ 26.724	1348.937 $\pm$ 67.420	1712.287 $\pm$ 89.255	646.785 $\pm$ 39.526	2359.072 $\pm$ 118.310	1905.249 $\pm$ 101.937	550.651 $\pm$ 33.962	2455.900 $\pm$ 125.945

The mean bearing different superscripts (a,b,&c) within the columns differs significantly ($p < 0.01$)

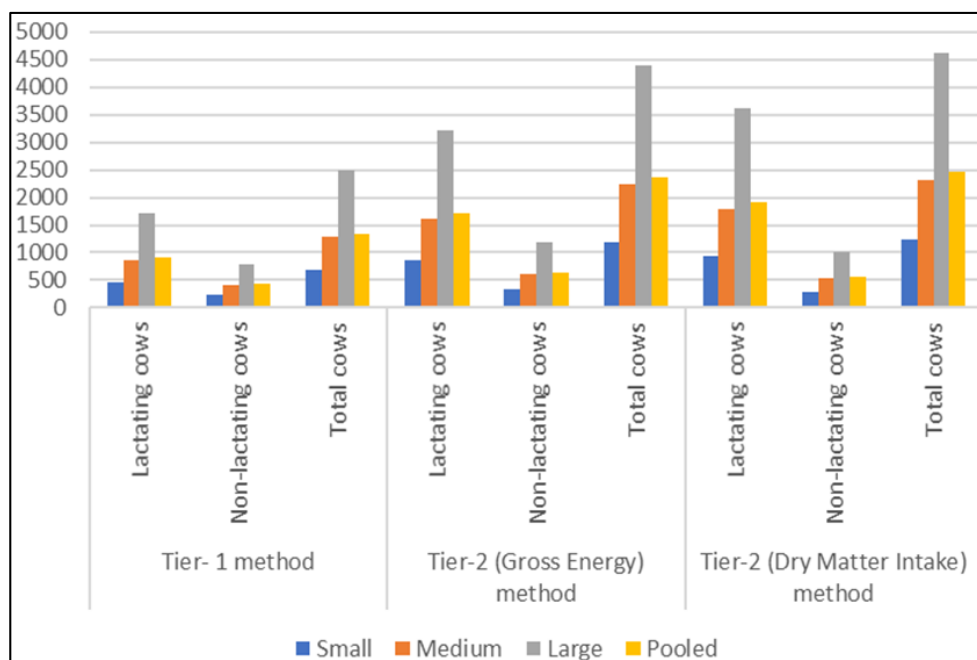


Fig 1: Mean values of Methane emission of different livestock farming system using IPCC Tier-1, Tier-2 (Gross Energy) and Tier-2 (Dry Matter Intake) method.

Conclusion

The study concludes that methane emissions from enteric fermentation in the Nagpur district are strongly dependent on farm size, with larger livestock farming systems contributing disproportionately higher emissions. The significant differences ($p < 0.01$) observed across farm categories highlight the need for differentiated mitigation strategies. Emission estimates obtained through Tier-2 approaches, especially Tier-2(Dry Matter Intake), were notably higher than Tier-1 estimates, emphasizing the importance of detailed and region-specific data for accurate quantification. Lactating cows were identified as the major emission contributors, suggesting the need for focused interventions in this group. From a policy perspective, promoting climate-smart livestock practices such as improved feed efficiency, inclusion of methane inhibitors, and balanced breeding strategies involving indigenous and crossbred cows is crucial in reducing methane emissions while sustaining productivity.

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