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Research Article

Estimation of enteric methane emission factor in cattle species in Ethiopia using IPCC tier 2 methodology

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Abstract

Aims: The livestock production system contributes to global climate change directly through the production of methane (CH_4) from enteric fermentation, CH_4 and nitrous oxide (N_2O) from manure management. Enteric CH_4 emission from livestock is the major contributor to greenhouse gas (GHG) emission from livestock in Ethiopia. National inventory and reporting of enteric CH_4 emission in cattle species in Ethiopia are based on default emission factor (tier 1 methodology) developed by Intergovernmental Panel on Climate Change (IPCC). These enteric CH_4 emissions are influenced by different factors such as livestock feed characteristics, livestock management, and livestock production and productivity. Hence, its estimation requires accurate data specific to the condition of the livestock production system in the country. The objective of this study was to estimate enteric CH_4 emission from cattle species in Ethiopia.

Methodology: Enteric CH_4 emission was estimated using IPCC tier 2 methods using input data collected through survey and literature data on livestock and feed characteristics in Ethiopia.

Results: Results indicated that enteric CH_4 emission factors among indigenous cattle were 30.27, 18.52, 31.55, 29.82, 32.48, and 12.60 kg per head per year for matured females >2 years old, females 1-2 years, bullocks/oxen, breeding bulls >2 years old, males 1-2 years and calves <1 year's old, respectively. Among crossbred dairy cattle, enteric CH_4 emission factors were found to be 36.21, 19.98, 27.90, 25.51, 5.45 kg per head per year for matured females >2 years, females 1-2 years, matured males >2 years, males 1-2 years and calves <1 year's age, respectively. The weighted average CH_4 emission factor for indigenous cattle and crossbred dairy cattle were 26 and 30.71kg/head/year, respectively.

Conclusion: Enteric CH_4 emission factors for nondairy indigenous and crossbred cattle using IPCC tier 2 methodology were lower when compared to IPCC tier 1 estimate. Our study recommends IPCC tier 2 methodology, for national enteric CH_4 emission inventory and reporting for cattle species in Ethiopia. The present study was based on limited survey and published data, uncertainties may have presented with, some of production and performance data. Further research is required to estimate enteric CH_4 emission using more detailed cattle production and feed characterization data.

Introduction

The livestock production system contributes to global climate change directly through the production of CH_4 from enteric fermentation and manure management and N_2O from manure management. Methane is the most important greenhouse gas that traps over 21 times more heat per molecule compared to carbon dioxide CO_2 [1]. One of the largest biogenic (i.e., produced by a living organism) sources of CH_4 is digestive fermentation from ruminant animals [2]. CH_4 is emitted through methanogens under anaerobic conditions through enteric fermentation and in manure storage. In general, enteric methane production by ruminants is influenced by dietary characteristics (example daily feed intake, type of diet, and

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diet composition), livestock production (such as live weight, growth rate, stage of production, reproduction, and feeding situation) Hence its estimation requires accurate data specific to the condition of the country.

Currently, in Ethiopia, national inventories of CH_4 emission from enteric fermentation are estimated using the Intergovernmental Panel on Climatic Change (IPCC) tier-1 methodology, which calculates CH_4 emissions for each animal category by multiplying the animal population by the default emissions factor associated with the specific animal category [3]. Weight, age, sex, and feeding systems are assumed similar within the animal category. Using these estimates, it has been determined that Greenhouse Gas (GHG) emission from Ethiopian cattle accounts for 65 Mt CO_2e in 2011, enteric fermentation accounting for 90% of total livestock emissions [4]. According to [3], countries using an IPCC tier-2 methodology can improve emission estimates and reduce uncertainties as this methodology considers several variables influencing enteric CH_4 emissions, including weight, age, gender, feeding systems, etc. As enteric fermentation is a key source of GHG emissions in the agricultural sector in Ethiopia, adopting the IPCC Tier-2 methodology will improve our ability to determine the mitigation value of various on-farm practices. Several countries for example Canada, the United States, and Australia are already using Tier-2 methodology. The objectives of this study were to estimate enteric CH_4 emissions from the Ethiopian cattle population using the IPCC Tier-2 methodology and further, to compare these values to emission factors generated by the IPCC Tier-1 methodology.

Materials and methods

Cattle performances and production practices

A survey posing questions regarding cattle management, feed, and feeding practices was prepared and administered to smallholder farmers. When available, data from producer surveys were utilized to describe the production environment and associated performances of the cattle category. Additional information was sought from personal communication with a researcher at federal and regional research institutions, as well as from district-level development workers.

The survey and published reports provided information in the following areas: average body weight, mature weight, daily weight gain, average daily milk yield, milk fat content, type of production environment (pasture vs. confinement), pregnancy rates, type and quality of feed fed for each cattle sub-category. When not provided by the survey data for example live weight for indigenous cattle (Table 1), daily weight gain (Table 2), and Digestible Energy (DE%) values of the feedstuffs were obtained from the published literature [3,5]. For crossbred dairy cattle, the live weight of the animal was obtained by taking heart girth measurements from selected dairy farms around Addis Ababa milk shade for defined IPCC sub-categories. However, for indigenous cattle average live weight was generated from data collected from published and research centers reports of different indigenous cattle breeds in Ethiopia (Table 1). DE% value of 50% for indigenous cattle on grazing and crop residue, while DE% value of 65% for crossbred dairy cattle under improved feed, supplementation with concentrate diet was used [3,5]. The average daily growth rate of growing animals for both indigenous cattle and crossbred dairy cattle was obtained from a published report (Table 2).

Table 1: Live weight data from literature sources for nondairy indigenous cattle breed.

Breed	Weaning weight (kg)	1-2 years weight (kg)		Adult weight (kg)		Reference
	Calves <1 year	Male	Female	Male	Female	
Begait	92	257	189	335	295	[7-10]
Boran	157	-	-	300	285	[8,11,12]
Horro	88	-	-	370	250	[13-5]
Zebu	153	216	197	274	250	[7,12,16]
Ogaden	91	-	-	285.7	172	[17]
Afar	-	-	-	329	251	[18,19]
Average	116.20	236.50	193.00	315.62	250.47	

Table 2: Average daily growth and milk yield per day for indigenous cattle and crossbred dairy cattle breed in Ethiopia.

Parameters	Indigenous cattle breed				Crossbred dairy cattle			
	Borena	Begait	Horro	Fogera	50%	62.5%	75%	87%
Average daily growth, gram/day	401.40	385.30	377.60		302.70	342.70	323	301
Daily milk yield, liters/ day/animal	1.70	-	-	2.32	8	-	-	-

Source: [13,14,16,20,21]

Emission estimates

Enteric CH_4 emissions factors were calculated using IPCC Tier-2 equations [3]. In doing so, some assumptions were made:

- Methane conversion rates (Ym), percent of gross energy intake applied to enteric CH_4 emission estimates were 6.5% for both indigenous and crossbred dairy cattle [3];
- Subcategory used were matured females >2 years, females 1-2 years, males >2 years, bullocks/oxen, males 1-2 years, and calves <1-year-old.
- To calculate the energy for work for indigenous cattle, bullock or oxen was assumed to work for 1.37 hours per day other cattle for about 0.55 hours per day [3].

The amount of CH_4 produced, also known as the Emission Factor (EF), was calculated using the Tier-2 equations and expressed as kg per head per year. For most categories, the time that cattle are in a given production environment is equal to one a year but for young animals, 180 days were used [3].

CH_4 emission factor estimate for each cattle sub-category was multiplied by their proportional contribution of sub-category to the total population of that category to arrive at weighted average CH_4 emission factor. The proportion of each sub-sub category to total population was derived from cattle population data from the Central Statistical Authority of Ethiopia [6] by dividing sub-category population number to total population number of that category.

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The animal performances information obtained from the survey and published literature were used to estimate Gross Energy (GE) required for each cattle subcategory. Although not used in the calculation to estimate enteric CH_4 emissions, feed intake was checked and compared with the weight of the animal in each subcategory by dividing the GE for each category by a default energy density of 18.45MJ/ kg, as suggested by [3].

Estimation of Gross Energy (GE) intake

Average GE intake was estimated from net energy requirement for maintenance, activity, work, lactation, pregnancy, and net energy for growth for young animals using IPCC tier-2 methodology. The equation used to estimate Gross Energy intake (GE) is as follows:

$$GE = \frac{\left\{ \frac{\left(NEm + NEa + NEwork + NEl + NEp\right)}{REM} + \frac{NEg}{REG} \right\}}{DE\% / 100}$$

Where;

GE= Gross energy in megajoule, (MJ/animal/day)

NEm=net energy for maintenance

NEa= Net energy for activity

NEwork= Net energy for work

NEl= Net energy for lactation

NEp= Net energy for pregnancy

NEg=Net energy for growth of young animals

REM=Ratio of net energy available in the diet for maintenance to digestible energy consumed

REG= Ratio of net energy available in the diet for growth to digestible energy consumed

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

Estimating enteric CH4 emission factor

Methane emission factor from enteric fermentation in cattle was calculated using estimated GE intake and methane conversion factor (Y_m) as input in the following equation;

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

Where;

EF= Methane emission from enteric fermentation, kg CH_4/ animal/year

GE= Gross energy intake, MJ/head/day

Y_m= Methane conversion factor, percent of gross energy in feed converted to methane [3], Y_m value of 6.5% reported by [3] was used for all sub-categories.

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

Comparison with IPCC tier 1

The computed enteric CH_4 emission factors obtained using IPCC Tier-2 methodology were compared with IPCC tier-1 CH_4 emission factors reported for other cattle in Africa [3]. The IPCC tier-1 emission factors (kg of CH_4 per head per year used for comparison were: 41 kg/head for mature females grazing and bullock under stall feeding, and 49 kg/head for bull grazing [3].

Result and discussion

The result from the study (Table 3) indicated that enteric CH_4 emission factors using IPCC Tier-2 approach for indigenous cattle were 30.27, 18.52, 31.55, 29.82, 32.48 and 12.60, Kg per head per year for mature females >2 years, females 1-2 years, bullocks/oxen, mature male >2 years, males 1-2 years and calves <1-year-old, respectively. For crossbred dairy cattle, enteric CH_4 emission factors were found to be 36.21, 19.98, 27.90, 25.51, 5.45 kg per head per year for mature females >2 years, females 1-2 years, mature males >2 years, males 1-2 years and calves <1 year's old, respectively. The weighted average emission factor for indigenous cattle and crossbred dairy cattle were 26.00 and 30.71 kg/head/year, respectively. Crossbred dairy cattle was higher initial body weight, higher milk yield compared with indigenous cattle leading to increased energy requirements for maintenance and for production (Table 3). However, on the base of CH_4 per unit of milk yield crossbred dairy cattle emit less compared to indigenous.

Enteric CH_4 emission factor obtained for females >2 years old (indigenous cattle) in the present study is similar with emission factor ranging from 27.1 to 34.1kg/head/year reported in Kenya for female cattle >2 years old but enteric CH4 emission factor for males >2 years age in the present study is lower than emission factor of 35.9 kg/year reported for male greater than 2 years old in Kenya [22]. Emission factors for indigenous cattle females of 1-2 years age class (18.52 kg CH_4 /head/year) in the present study were close to the mean enteric CH_4 emission factor of 23kg reported for females 1-2 years old in Kenya in cattle species [22]. Kouazounde, et al. [23] reported an average CH_4 emission factor of 39kg per head for cattle from Benin, which is higher than the emission factor for mature females in the present study. Moreover, the enteric CH_4 emission factor for indigenous cattle (nondairy cattle) in the present study were lower than enteric CH_4 emission factors ranging from 31.70 to 106.70 kg/head/year with a weighted average of 65.13kg CH_4/head/year [24] reported in South Africa for non-dairy cattle. The variation in emission factors estimated in the present study from literature reports was attributed to the difference in breed [23], feed intake and feed types [25,26], animal management, and body size [3,25].

For crossbred dairy cattle, enteric CH_4 emission factors in the present study were lower than enteric CH_4 emission factors ranging from 83.70 to 112.36kg CH_4/head/year [24,27] reported

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Table 3: Methane emission factor for indigenous and crossbred dairy cattle in Ethiopia.

Sub-category	Average live Weight, kg	Average daily Weight Gain, kg/day	Average Milk yield, kg/day	Feeding situation	Fat content of milk, %	Average work, hours/day	PR, %	DE%	DMI, kg/day	GE, MJ/day/head	Y_m in %	CH_4 EF (kg/head /year	Population mix[1] %
Nondairy Indigenous cattle													
Female >2 years old	250.47	-	2.0	Grazing	4	0.55	45	50	3.80	70.99	6.5	30.27	37
Female 1-2 years	193.00	-		Grazing	-	0.55	-	50	2.15	43.43	6.5	18.52	9.3
Bullocks/ oxen	315.62	-		Grazing	-	1.37	-	50	4.0	74.00	6.5	31.55	25.4
Males >2 years	315.62	-		Grazing	-	0.55	-	50	3.63	69.95	6.5	29.82	3.1
Male 1-2 years	236.50	0.4		Grazing	-	0.55	-	50	2.32	76.18	6.5	32.48	7.5
Calve <1 years	116.20	0.4		Stall feed	-	0.00	-	50	1.16	29.56	6.5	12.60	17.7
Weighted average												26.53	100
Crossbred dairy cattle													
Females >2 years	450	-	8.0	Pasture	4	0.55	50	65	4.72	87	6.5	36.21	64
Females 1-2 years	270	-	-	Pasture	-	0.55	-	65	2.66	49	6.5	19.98	27
Males >2 years	350	-	-	Pasture	-	0.55	-	65	3.41	63	6.5	27.90	2
Male 1-2 years	224	-	-	Pasture	-	0.55	-	65	3.69	68	6.5	25.51	6
Calves <1 years	90	0.303	-	Stall-feed	-	-	-	65	1.41	26	6.5	5.45	1
Weighted average												30.70	100

PR= Pregnancy rate; DMI=Dry matter intake; EF= Enteric methane emission factor; DE=Digestible energy, GE=Gross energy. Grazing= animal grazing on communal grazing land. Pasture= animal grazing on small areas with limited movement; Stall-feed=animal managed indoor; [1]population mix = proportion of each sub-sub category to the total population

for dairy cattle in South Africa. This might be attributed to the live weight of these cattle could be higher than that of the cattle in our study (and that voluntary intake would have been commensurately larger). A higher emission factor of 126 kg/head/year was also reported for dairy cows in Canadian dairy cattle [28] using the same IPCC Tier-2 methodology. These variabilities might be related to breed and body size differences in energy requirement for maintenance, production, and or locomotion.

The enteric CH_4 emission factor of 19.98 kg/head/year for crossbred dairy cattle of 1-2 years of age in the present study was lower than the enteric CH_4 emission factor of 62 kg /head/year for Canada dairy cattle [28]. A higher emission factor of 72 kg CH_4 /head/year was also reported [29] for dairy heifers in Canada using IPCC Tier-2 methodology. In a similar way, a higher emission factor of 73 kg of CH_4 /head/year was also reported in the United States for beef heifers, 12–23 months of age, using the same IPCC Tier-2 methodology (Inventory of US Greenhouse Gas Emissions and Sinks, 1990–2000). These lower emission factors in Ethiopian crossbred dairy cattle and heifers compared to the above reports could be attributed to lower feed intake as a result of lower body weight [25], the difference in feed characteristic [25,26], and breed and age differences [23].

Comparison of methodologies

A comparison of enteric CH_4 emission factors using IPCC Tier-1 and IPCC Tier-2 methodology is given in Table 4. In general, IPCC Tier-2 estimates for enteric CH_4 emissions in the present study were lower than those generated using IPCC Tier-1 methodology. For example, emission factors for mature indigenous nondairy females using IPCC Tier-2 were lower than IPCC Tier-1 by 26%. Moreover, IPCC Tier-1 estimates were 39% and 23% higher for bulls grazing and bullock when compared with the result obtained using IPCC Tier-2 methodology. In general, the lower CH_4 emission factors obtained using IPCC tier-2 method compared to IPCC tier-1 values in the present study are attributed to the use of country-specific data on production, live weight, and average daily weight gain. This can be expected as IPCC Tier-1 was not based on country-specific data and may not account for differences in performances [3]. The weighted average CH_4 emission factors obtained in the present study for indigenous and crossbred dairy cattle using tier-2 methodology were lower than the values generated using the IPCC tier-1 method by 15% and 36%, respectively (Table 4).

Conclusion

Enteric CH_4 emission factors for nondairy indigenous and crossbred dairy cattle were lower compared to others in the

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Table 4: Comparison of emission factor for nondairy indigenous cattle using IPCC tier-2 and IPCC tier-1 methodology.

Category	Tier 2 Kg/year/ head	Tier 1 Kg CH4/year/ head	Difference % (Tier-1)-(tier-2)/tier-1*100
Mature cows grazing	30.27	41	26
Draft bullock/oxen	31.55	41	23
Bulls grazing	29.82	49	39
Calves	12.60	16	21.25
Weighted average for indigenous	26.53	31.24	15
Weighted average for crossbred	30.70	48.20	36

Tier 1 value of weighted average for crossbred dairy cattle was obtained from [4] (adapted from [3])

literature, which is attributed to the difference in breed, feed intake and feed types, animal management, the body size difference in energy requirement for maintenance, production, and or locomotion. Moreover, the enteric CH_4 emission factor for nondairy indigenous cattle in the present study using IPCC tier-2 was lower compared to IPCC tier-1 estimates. The lower enteric CH_4 emission factor using IPCC tier-2 methodology compared to IPCC tier-1 estimate was attributed to the use of cattle characterization data generated in Ethiopia livestock production system. Our study recommended the use of IPCC tier-2 methodology in methane emission inventory preparation and reporting for cattle species in Ethiopia. The present results were the first attempts to estimate enteric CH_4 emission using IPCC tier-2 methodology, based on limited published data on production and feed characterization data. Further research is required to improve emission factors for Ethiopian livestock production using detailed livestock and feed characterization data in IPCC tier-2 and recent advanced technologies.

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Conflict of interests

The authors declared that no potential conflict of interest is reported regarding the subject matter of this manuscript either for financial, commercial, or intellectual purposes.

Authors' contribution

Both authors contributed their time in the idea generation, proposal writing, data collection, data analysis, data interpretation, and manuscript drafting (writing) and, approved for submission.

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