RESEARCH ARTICLE

Country-specific emission factors for methane emission from enteric fermentation: a case study from a non-annex 1 country

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Abstract: Methane emission from enteric fermentation is a subcategory considered under the Agriculture sector greenhouse gas emissions under the United Nations Framework Convention on Climate Change (UNFCCC). So far, most non-annex 1 member countries have used the default IPCC 1996 revised guidelines in estimating such emissions. The latest IPCC 2006 revised guidelines for national greenhouse gas inventories provide better guidelines for developing country-specific emission factors. Country-specific methane emission factors were developed for estimating methane emission from enteric fermentation in livestock in Sri Lanka, using a Tier 2 approach with energy calculations (IPCC, 2006) based on country-specific activity data. Each animal category was further subdivided for the analyses, and emission estimates incorporated population characteristics in the different agro-climatic zones of the country. Separate emission factors were calculated for sub categories within the local (indigenous) and improved (Indian and European) breeds. The population-weighted methane emission factor (50 kg head^{-1} yr^{-1}) estimated for dairy cows (i.e. lactating females) was lower than the IPCC default value. The methane emission factors calculated for other cattle categories ranged between 11 – 58 kg head^{-1} yr^{-1}. However the population-weighted emission factor (32 kg head^{-1} yr^{-1}) was slightly higher than the IPCC default value (27 kg head^{-1} yr^{-1}), as the proportion of the calves in the other cattle population was relatively lower (~47 percent) than what the IPCC default emission factor has considered. Overall, the population-weighted emission factors for buffaloes (49 kg head^{-1} yr^{-1}) and sheep (3 kg head^{-1} yr^{-1}) were lower than the IPCC default values.

Keywords: Climate change, enteric fermentation, greenhouse gas inventory, IPCC Tier 2 methodology, livestock, methane emissions.

INTRODUCTION

Anthropogenic climate change and increased levels of greenhouse gases (GHG) in the atmosphere led to the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) at the Rio Earth Summit held in 1992. Agriculture has been identified as one of the key source/sink categories under the UNFCCC, and methane (CH_4) emissions from enteric fermentation is a sub category under Agriculture. Under the UNFCCC, the member countries are expected to submit a national greenhouse gas inventory. Annex 1 (developed) countries are required to submit an annual national greenhouse gas inventory. Although an annual submission is not required from the non-annex 1 (developing) countries, they are also expected to submit periodic greenhouse gas inventories and are encouraged to develop their own methodologies and emission factors, wherever applicable.

So far the developing countries have been mostly using the Revised 1996 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories, following from the decision 17/COP 8 (UNFCCC, 2003). In addition to the default IPCC 1996 methodology (IPCC 1997a;b;c), some developing countries have also been using the IPCC Good Practice Guidance (IPCC 2000; 2003). The latest IPCC 2006 guidelines for national greenhouse gas inventories are more elaborate, and provide guidelines for developing country specific emission factors under certain GHG source/sink sub categories.

The main objective of this study is to develop country-specific methane emission factors for enteric fermentation in major livestock categories in Sri Lanka, following the Tier 2 methodology under the IPCC 2006 guidelines.

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Table 1:   Livestock population in different agro ecological zones of Sri Lanka in 2002 and 2014

Category	Dry Zone	Wet Zone	Intermediate Zone	Total
2002				
Cattle	591,997	217,407	277,185	1,086,589
Buffaloes	132,121	65,369	89,936	287,426
Sheep and goat	182,268	38,076	44,240	264,584
Swine	26,857	15,725	15,770	58,352
Poultry*	4,331,663	4,458,197	4,386,181	13,176,041
Total	5,264,906	4,786,774	4,813,312	14,872,992
2014				
Cattle	658,200	236,150	210,430	1,104,780
Buffaloes	177,280	83,690	59,720	320,690
Sheep and goat	186,480	85,580	38,030	310,090
Swine	52,700	37,670	14,840	105,210
Poultry*	4,074,685	5,422,550	7,144,875	16,642,110
Total	5,149,345	5,865,640	7,467,895	18,482,880

* Chickens, ducks, and turkey.

Source: Department of Census and Statistics (*http://www.statistics.gov.lk/agriculture/*)

Agriculture is a major economic sector in the developing countries in South Asia. In Sri Lanka, the overall agriculture sector and livestock sub sector contribute 11.1 % and 1.0 %, respectively to the gross domestic product (GDP) (Central Bank of Sri Lanka, 2013). Although the livestock sector has been used for the dairy requirement of the country, the major part of the requirement is still met by dairy imports (Abeygunawardena *et al*., 1997; Bandara *et al*., 2011). Sri Lanka, as a tropical island in the Indian Ocean, has been experiencing various impacts of climate change. The country has been a member of the United Nations Framework Convention on Climate Change (UNFCCC) since its ratification in 1993. So far, Sri Lanka has produced two national communications including sector wise greenhouse gas inventories. The current study analyses the country-specific activity data and other information to derive country-specific methane emission factors for enteric fermentation using the IPCC Tier 2 methodology (IPCC, 2006), to supplement and compare with the existing default values given by the IPCC (2006) for livestock in the Indian subcontinent.

Methane emission from enteric fermentation

Livestock populations with ruminants emit methane due to the anaerobic digestive process in the forestomachs (i.e. fermentation). Up to 12 % of dietary energy in ruminant livestock can be lost in the form of methane (Blaxter, 1967), and such methane production from ruminants could range from 250 to 500 liters a day (Johnson & Johnson, 1995). Enteric fermentation contributes to 17 % of the global methane emissions (Knapp *et al*., 2014). The amount of CH_4 emitted depends on the body size, metabolism, activity level of the animals, and their feed quality, etc. Low quality forage including grasses causes higher amounts of CH_4 emission, and most of the indigenous/local cattle and buffaloes in Sri Lanka feed on low quality grasses, straw, and other crop residues (Zemmerlink *et al*., 1999). Improved (European and Indian) cattle breeds are normally given higher quality, concentrate feed, mostly consisting of coconut cake and rice bran (Buvendran, 1977) and they have higher digestive efficiencies with reduced CH_4 emissions.

In Sri Lanka, cattle and buffaloes are the major livestock groups, while goats, swine, and sheep remain as the minor groups (Table 1). Cattle, buffaloes, and sheep are the ruminant categories, and country-specific emission factors for methane emissions from enteric fermentation were derived considering the sub categories of these animals.

METHODOLOGY

In deriving the methane emission factors, population characteristics of the different livestock categories were studied using population data from the agriculture census in 2002 (*http://www.statistics.gov.lk/agriculture/*) (Table 1), which was the last comprehensive census on livestock in Sri Lanka including information on local (i.e. indigenous) and improved breeds.

Out of all cattle breeds, indigenous cattle constituted about 85 % of the population, while improved breeds constituted 15 %. Indigenous cattle constituted 93, 86.2, and 76 % of the total population in Dry, Intermediate,

Table 2: Information relevant to prominent livestock types in Sri Lanka

Animal breed	Weight (kg)			Weight gain per day (g)	Milk production per lactation (Litres)	Percent fat in milk	Wool production (kg yr^{-1})
	Adult males	Adult females	Calves*				
Cattle							
Friesian	360 – 410	250 – 300	32	550	3000 – 3500	3.0 – 3.5	--
Ayershire	320 – 360	225 – 270	30		2750 – 3000	4.0	--
Jersey	270 – 320	180 – 225	25	410	2250	4.5 – 5.4	--
Australian	270 – 320	180 – 225	27		2000	4.5 – 5.4	--
Sahiwal	225 – 270	180 – 200	22	375	1100	4.5	--
Red Sindhi	200 – 225	135 – 160	20		1000	4.5 – 4.9	--
Tharpakar	225 – 270	180 – 200	25		1000	4.2 – 4.7	--
Indigenous	160 – 200	140 – 180	18	260	450	4.2 – 4.7	--
Bufflaloes							
Murrah	600	500	35	600	--	7.6	--
Nilli Ravi	600	500	33	550	--	7.8	--
Indigenous	200 – 225	180 – 200	22	375	300	7.2 – 7.7	--
Goats							
Jamnapari	35 – 45	30 – 32	2.5		--	5.6 – 6.0	--
Sannan	34 – 43	23 – 34	2.0	110	375	3.6	--
Indigenous	--	--	1.6	90		4.2	--
Sheep							
South Down	40 – 45	30 – 32	--		--	--	1.5 – 2.0
Red Madras	30 – 40	20 – 30	2 – 3				
Jaffna sheep	15 – 20	7	1.2		--	--	--
Indigenous	15 – 20	7	1.2		--	--	--
Swine							
Landacre			1.4	450			
Large white	135 – 200		1.2	400			
Indigenous		--	0.8	225	--	--	--

* Weight at birth; -- not relevant or data unavailable. Source: Ministry of Livestock Development, 2008 (*unpublished data*)

and Wet Zones, respectively. Similarly, indigenous buffaloes accounted for 92.2, 92.3, and 84.7 % of the total buffalo population in the Dry, Intermediate, and Wet Zones, respectively. Improved buffalo population in the country was only about 9 % of the total buffalo population. From 2002 to 2014, the total numbers in different livestock categories have increased with a marked reduction in the numbers of ruminant livestock in the Intermediate Zone.

Some information on the local and improved cattle and other livestock breeds are given in Table 2. The information given has the average values at national scale. For the inventory analyses district-wise populations of different livestock categories [i.e. males, females (lactating *versus* non lactating), calves] were considered. Since the different categories of cattle and buffaloes comprise the majority of the livestock in Sri Lanka (Table 1), this study focused mostly on estimating the country-specific CH$_4$ emission factors for the sub-categories of these two animal groups. In addition, the emission factors for sheep and goats were estimated considering the populations of the latter two groups together.

Country-specific emission factors were derived using the nationally available breed- and subpopulation information; each animal category was further

subdivided for the analyses. It was considered that all the cattle in Sri Lanka are used for dairy (not meat) production, and the cattle population was subdivided as mature dairy cows, mature bulls, and growing cattle (i.e. calves, heifers). The average milk production in improved and local cows in different ecological zones (i.e. dry, intermediate, wet hilly, and other wet regions; Table 3) were considered in estimating the final weighted average for each animal subcategory in the country. For estimating the CH_4 emission factor from enteric fermentation, a Tier 2 approach was used in gross energy calculations (IPCC, 2006) based on country-specific activity data, including the information provided in Tables 1, 2 and 3.

The estimation of CH_4 emission factor for different subcategories of cattle and buffaloes incorporated the calculation of the following energy components using the algorithms detailed in IPCC (2006): maintenance energy (NE_m) calculation based on the body weights of different subcategories of the livestock (Table 1); activity energy (NE_a) calculation concerning the maintenance energy and the energy expenditure in finding food; growth energy (NE_g) for the young considering average daily weight gain and live average- and mature body weights (Table 2); lactation energy (NE_l) calculation using the milk production and the percentage of milk fat (Tables 2 and 3); work energy (NE_{work}) based on the body weight (Table 2) and the number of hours spent on draft power; pregnancy energy (NE_p) as a fraction of the maintenance energy; energy requirement for annual wool production (NE_{wool}; for sheep only); ratios of net energy available in the diet for maintenance and growth with respect to digestible energy consumed (i.e. REM and REG, respectively [(IPCC, 2006); equation (1)]; digestible energy corresponds to the proportion of energy in the feed not excreted in the faeces (IPCC, 2000).

The final gross energy (GE) calculation involved all the above different components of energy and the ratios REM and REG [(IPCC, 2006); equation (1)]. The estimated GE was then used for deriving the final CH_4 emission factors for different subcategories of animals [equation (2); (IPCC, 2006)].

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

...(1)

Where:
GE = gross energy for cattle and buffaloes, 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 consumed
NE_g = net energy needed for growth, MJ day⁻¹
NE_{wool} = net energy required to produce a year of wool, MJ day⁻¹ (considered only for sheep)
REG = ratio of net energy available for growth in a diet to digestible energy consumed
DE % = digestible energy expressed as a percentage of gross energy

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

...(2)

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.

The above detailed components of gross energy (i.e. maintenance energy, activity energy, lactation energy, growth energy, pregnancy energy, etc.) and CH_4 emission factors were estimated for different ruminant livestock categories. All the energy estimates and CH_4 emission factors were estimated separately for the improved and local populations of lactating females, non-lactating females, mature bulls, and calves (less than 3 years).

Final CH_4 emission factors were estimated for the two main IPCC categories: dairy (i.e. mature cows that are producing milk in commercial quantities for human consumption), and other cattle (i.e. cows not currently lactating, bulls, and calves). The final CH_4 emission factor for other cattle was calculated as a population-weighted estimate based on the population of each subcategory involved (Table 5). Forty seven percent of the other cattle in the local population were calves. It was assumed that calves less than 3 months emit a negligible amount of CH_4 (and thus avoided in the estimation of CH_4), and assumed to be 20 % of the total calf population.

Table 3:   Average daily milk production* (kg head^{-1} day^{-1})

Agro-ecological zone	Local cows	Improved cows	Buffaloes
Dry	1.0	2.7	1.0
Intermediate	1.0	3.0	0.7
Wet hilly	2.0	6.0	1.1
Low country wet	1.3	3.4	0.8

* These estimates were based on the population and milk production data at district level [Source: Census of Agriculture 2002, Department of Census and Statistics (*http://www.statistics.gov.lk/agriculture/*)]; certain estimates were amended considering the values observed for main dairy production systems within the country (Ibrahim *et al*., 1999; Bandara, 2001; Ranaweera, 2009)

Due to lack of exact information, several assumptions had to be made in estimating certain energy components using the IPCC (2006) Tier 2 guidelines. In estimating the activity energy, the IPCC (2006) has provided default activity coefficients of 0 and 0.17 (dimensionless) for stall-fed [i.e. confined to small areas (tethered, pen, or barn)] and pasture-fed cattle, respectively; the activity coefficient for pasture fed cattle given by the IPCC (2006) was modified by using multiplication factors of 0.4 and 0.5 for improved and local cattle, respectively, as they are stall-fed (and fodder- and concentrate-fed) during certain periods of their life. In estimating the work energy for mature cattle and buffaloes, the number of work hours per day was assumed as 1.2 hrs per day considering the very low annual use of draft power within the country. The work energy and pregnancy energy coefficients given by the IPCC (2006) for cattle and buffaloes were further modified considering the fraction of draught animals in the population (i.e. 0.6 and 0.8 in improved and local cattle populations, respectively) and the percentage of females giving birth in a year (i.e. 70 and 85 % in improved and local cows, respectively). The average calf weight for each livestock category was estimated based on the birth weights and daily weight gains (Table 2), considering the population of growing animals/calves under 3 years of age. The digestible energy was considered as 70 % and 55 % for improved and indigenous cattle, respectively, based on the expert opinion and the percentages suggested by IPCC (2006); a lower methane conversion factor (i.e. 5.5 %) was considered for the improved cattle, compared to the local population (i.e. 6.5 %), based on the value ranges given by IPCC (2006).

The improved buffaloes constituted only 9 % of the total population, and thus weighted emission factors were derived using the Tier 2 method for dairy and other buffaloes considering the percentage of local and improved buffaloes in the total population. Sixty percent digestible energy was assumed for improved buffaloes,

while 55 % digestible energy was assumed for local buffaloes based on expert opinion; a methane conversion factor of 6.0 % was considered.

RESULTS AND DISCUSSION

The estimates of energy components in different livestock categories using IPCC (2006) guidelines involved elaborate calculations; the estimates made for cattle are provided in Table 4. The methane emission factors estimated by including the energy estimates in equation 1 and equation 2 are given in Table 5.

Out of all the cattle subcategories, indigenous mature bulls had the highest methane emission factors. Due to occasional use in draft power and high maintenance requirement due to larger size and body weight, indigenous mature bulls had higher CH_4 emission factors compared to the cows. The emission factor for the improved dairy cows is slightly lower than that for the improved bulls. Improved bulls weighed between 200 – 400 kg, requiring more maintenance energy compared to the cows and indigenous bulls. The overall gross energy intake and CH_4 emission factors were lower for the cows and bulls of the improved varieties compared to the indigenous ones, due to higher digestible energy associated with the feed given to the improved cattle.

However, the improved calves had higher emission factors compared to the indigenous ones, mostly due to the higher maintenance and growth energy associated with their larger body size and weight. The lactating cows in both indigenous and improved cattle had higher CH_4 emission factors compared to the non-lactating cows.

When a population-weighted emission factor was calculated for the dairy cattle in Sri Lanka considering the separate emission factors estimated for the improved and local cattle (Table 5), it yielded a value of 50 kg CH_4 head^{-1}, which is lower than the IPCC (2006) default

Table 4:   Estimated values for different energy components in cattle

Cattle sub category	Energy components (MJ day^{-1})						
	NE_m	NE_a	NE_l	NE_{work}	NE_p	NE_g	GE
Lactating cows (improved)	21.1	9	13	na	na	na	116
Lactating cows (local)	17.4	10	4	na	na	na	120
Non-lactating cows (improved)	17.6	14.1	na	na	2	na	90
Non-lactating cows (local)	14.5	13.6	na	na	2	na	114
Bulls (improved)	26	19.6	na	2	na	na	128
Bulls (local)	18.2	15.3	na	2	na	na	136
Calves (improved)	8	9	na	na	na	9	43
Calves (local)	6	7	na	na	na	4	25

NE_m = net energy for maintenance; NE_a = net energy activity; NE_l = net energy for lactation, NE_{work} = net energy for work; NE_p = net energy for pregnancy, NE_g = net energy for growth, GE = gross energy; REM used in GE calculation for improved and local cattle were 0.53 and 0.47, respectively; REG for improved and local cattle were 0.33 and 0.247, respectively; na - not applicable

Table 5:   CH$_4$ emission factors estimated for enteric fermentation in Sri Lankan cattle and buffaloes estimated using IPCC (Tier 2) method

Livestock category		CH$_4$ emission kg head^{-1} yr^{-1}
Dairy cattle		50* (IPCC default-58)
	- local	52
	- improved	42
Other cattle		32* (IPCC default-27)
	- local	32**
	- improved	26**
Estimates for sub categories:		
Non-lactating cows- local		49
	- improved	32
Mature bulls	- local	58
	- improved	46
Calves	- local	11
	- improved	16
Buffaloes		49* (IPCC default-55)
Dairy		65
Other buffaloes		44
Sheep		3 (IPCC default-5)

* Final weighted average, as described within the text
** weighted average based on the populations of sub categories

value of 58 kg CH$_4$ head^{-1} for the Indian subcontinent. The values for the other cattle subcategories ranged from 11 to 58 kg CH$_4$ head^{-1} (Table 5), yielding a population-weighted value of 32 kg CH$_4$ head^{-1}, which is slightly higher than the default value of 27 kg CH$_4$ head^{-1} given by the IPCC (2006).

The IPCC default emission factor for other cattle has considered non-lactating cows, bulls, and calves, with calves comprising a larger proportion among the other cattle categories; however, according to the cattle population census in Sri Lanka, the proportion of calves is less than 50 percent of the other cattle category,

contributing to a slightly higher emission factor for the other cattle. The population-weighted emission factors calculated for buffaloes (i.e. 49 kg CH_4 head^{-1}) and sheep (i.e. 3 kg CH_4 head^{-1}) were lower than the IPCC (2006) default values of 55 and 5 kg CH_4 head^{-1}, respectively. When the overall methane emissions calculated using the above emission factors from the three different ruminant livestock groups were compared, cattle, buffaloes, and sheep contributed to 72, 27, and 1 % of the total emissions, respectively.

According to the IPCC (1997a; b; c; 2006) guidelines and good practice guidance (IPCC, 2000; 2003), the member countries are encouraged to develop country-specific emission factors. Therefore, the methane emission factors derived for livestock subcategories in the current study will help improve the emission estimates in the next national greenhouse gas inventory to be produced by the country. However, due to lack of certain specific information required under the IPCC (2006) Tier 2 methodology, a few assumptions had to be made as described above; for instance, since there is no information available within the country on the daily use of draft power from cattle and buffaloes and the fraction of cattle exclusively grazing on pastures, the values had to be determined based on expert opinion. Therefore, the estimates from the current study might involve some uncertainty, although all the population data and majority of the coefficients used were country-specific. The emission factors estimated in the present study need to be validated in the future, once a country-wide measurement network for methane emissions from livestock is undertaken in Sri Lanka.

CONCLUSION

The methane emission factors estimated in this study using IPCC (2006) Tier 2 methodology are more representative of the national circumstances, as they are based on country-specific population characteristics. Overall, the estimated emission factors were lower than the default emission factors given by the IPCC (2006) for the Indian sub-continent except for other cattle, which had a slightly higher value. The methane emission factors estimated in this study will be helpful in improving the emission estimates of future national greenhouse gas inventories to be produced by Sri Lanka, and validation of the current estimates through adequate measurements will be worthwhile.

Acknowledgement

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