2004

Comparison of Enteric Methane Emissions in China for Different IPCC Estimation Methods and Production Schemes

Hongmin Dong
Chinese Academy of Agricultural Sciences

Xiuping Tao
Chinese Academy of Agricultural Sciences

Qing He
Chinese Academy of Agricultural Sciences

Hongwei Xin
Iowa State University, hxin@iastate.edu

Comparison of Enteric Methane Emissions in China for Different IPCC Estimation Methods and Production Schemes

Abstract

Accurate estimation of methane (CH4) emission (ME) from enteric fermentation in China is essential to establishing and maintaining a reliable global ME inventory and developing strategies to mitigate such emissions. Based on modern animal production statistics, i.e., feed quality and quantity data for different feeding systems, enteric methane emissions (EME) in China during the period of 1990 to 1998 were estimated using Intergovernmental Panel on Climate Change (IPCC) estimation methods for various production scenarios. The estimation was conducted based on: (1) Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Revised 1996 IPCC Guidelines) Tier 1, designated M1; (2) Revised 1996 IPCC Guidelines Tier 2, designated M2; (3) IPCC Good Practices Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC Good Practices Guidance) without incorporation of treated straw effect on ME, designated M3; and (4) IPCC Good Practices Guidance with incorporation of treated straw effect on ME, designated M4. The results revealed variability in ME among the four estimation methods and production conditions. Specifically, the estimated ME values in China for the peak emission year (1996) were 8,614; 11,039; 10,533; and 11,469 Gg, respectively, with M1, M2, M3, and M4, i.e., up to 33% difference from one method to another. These ME values for 1996 were 31%, 28%, 27%, and 20% higher than their respective values for 1990, the base year for evaluating future emission changes. Yellow cattle contribute more than 50% of EME in China. The methane emission factor was found to be 26% to 30% lower for yellow cattle fed treated residues than for those fed non-treated residues due to improved digestibility. This reduced ME factor translated into an estimated ME reduction of 935.7 Gg in 1996 and 1,253.5 Gg in 1998 for yellow cattle. To further improve the validity of EME estimation, it is suggested that certain quality control measures be taken, such as adjusting emission factors to reflect the changing livestock production systems and management practices, measuring ME factors in the field, and collecting and integrating current animal production statistics.

Keywords

Emission factor, Enteric fermentation, Greenhouse gas (GHG), Methane, Treated straw

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

This article is from *Transactions of the ASAE* 47, no. 6 (2004): 2051–2057.

COMPARISON OF ENTERIC METHANE EMISSIONS IN CHINA FOR DIFFERENT IPCC ESTIMATION METHODS AND PRODUCTION SCHEMES

H. Dong, X. Tao, H. Xin, Q. He

ABSTRACT. *Accurate estimation of methane (CH_4) emission (ME) from enteric fermentation in China is essential to establishing and maintaining a reliable global ME inventory and developing strategies to mitigate such emissions. Based on modern animal production statistics, i.e., feed quality and quantity data for different feeding systems, enteric methane emissions (EME) in China during the period of 1990 to 1998 were estimated using Intergovernmental Panel on Climate Change (IPCC) estimation methods for various production scenarios. The estimation was conducted based on: (1) Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Revised 1996 IPCC Guidelines) Tier 1, designated M1; (2) Revised 1996 IPCC Guidelines Tier 2, designated M2; (3) IPCC Good Practices Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC Good Practices Guidance) without incorporation of treated straw effect on ME, designated M3; and (4) IPCC Good Practices Guidance with incorporation of treated straw effect on ME, designated M4. The results revealed variability in ME among the four estimation methods and production conditions. Specifically, the estimated ME values in China for the peak emission year (1996) were 8,614; 11,039; 10,533; and 11,469 Gg, respectively, with M1, M2, M3, and M4, i.e., up to 33% difference from one method to another. These ME values for 1996 were 31%, 28%, 27%, and 20% higher than their respective values for 1990, the base year for evaluating future emission changes. Yellow cattle contribute more than 50% of EME in China. The methane emission factor was found to be 26% to 30% lower for yellow cattle fed treated residues than for those fed non−treated residues due to improved digestibility. This reduced ME factor translated into an estimated ME reduction of 935.7 Gg in 1996 and 1,253.5 Gg in 1998 for yellow cattle. To further improve the validity of EME estimation, it is suggested that certain quality control measures be taken, such as adjusting emission factors to reflect the changing livestock production systems and management practices, measuring ME factors in the field, and collecting and integrating current animal production statistics.*

Keywords. *Emission factor, Enteric fermentation, Greenhouse gas (GHG), Methane, Treated straw.*

Enteric fermentation is the third largest source of methane (CH_4) emission (ME) in China, following coal mining and rice cultivation. In 1990, China's enteric methane emission (EME) was estimated to account for 25% to 37% of its total ME from agricultural sources (ADB, 1999). The rapid economic development and improvement of living standards in China have led to the steady growth of its livestock production. From 1990 to 2000, livestock inventory in China increased 20.7% for cattle, 38.2% for sheep and goats, and 23.3% for swine, according to the China official government database (China Agriculture Yearbook, 1990−2001; China Animal Industry Yearbook, 2001). As a result, EME had been estimated to reach 13,800 Gg in 2000 and 16,900 Gg in 2020, surpassing that from rice cultivation (ADB, 1999). Because of China's large share of livestock production in the world (48% in swine, 8% in cattle, 12.5% in sheep, and 13.7 % in buffalo), accurate and timely determination of EME in China is not only essential to the Chinese national ME inventory, but equally important to the validity of the global greenhouse gas (GHG) inventory.

Recently, China has received some international support to carry out studies related to climate change, including collection of GHG inventory data. Historically, there were two main GHG inventory programs related to enteric emissions: the U.S. Country Studies Program (USCSP), and the Asia Least−Cost Greenhouse Gas Abatement Strategy Project (ALGAS). In USCSP, ME from ruminants in China in 1990 was estimated to be 5,805 Gg using the Revised 1996 IPCC Guidelines (RS−CCCCS, 1999) method. In ALGAS, in addition to using the Revised 1996 IPCC Guidelines, results from limited experiments of respiration chambers were included. The resultant estimated national ME from ruminant animals in China in 1990 ranged from 2,600 to 6,500 Gg (ADB, 1999). The wide range of ME arose from differences in feeding practice, namely, limited feeding vs. ad lib feeding and ingredients of the ration (i.e., with or without corn).

Article was submitted for review in January 2004; approved for publication by the Structures & Environment Division of ASAE in September 2004.

The authors are **Hongmin Dong, ASAE Member Engineer,** Professor, **Xiuping Tao,** Associate Professor, and **Qing He,** former Graduate Student, Department of Environmental Engineering, Institute of Agricultural Environment and Sustainable Development, Chinese Academy of Agricultural Sciences, Beijing, China; and **Hongwei Xin, ASAE Member Engineer,** Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa. **Corresponding author:** Dr. Hongmin Dong, Department of Environmental Engineering, Institute of Agricultural Environment and Sustainable Development, Chinese Academy of Agricultural Sciences, 12 Zhongguancun South Street, Beijing 100081, China; phone: 86−10−68919979; fax: 86−10−68919979; e−mail: donghm@mail.caas.net.cn.

Since the last estimation, the IPCC estimation method has been improved, especially with the IPCC Good Practices Guidance developed in 2000. Furthermore, substantial changes have taken place in animal population, production performance, composition and quality of rations, and management practices. These changes are expected to have considerable impact on the magnitude of ME in China.

The objectives of this study were: (1) to evaluate enteric methane emissions (EME) in China as affected by the various IPCC estimation methods and different production conditions, and (2) to identify factors contributing to the quality of enteric GHG inventory.

METHODOLOGY

IPCC RECOMMENDED ESTIMATION METHODS

Revised 1996 IPCC Guidelines

The Revised 1996 IPCC Guidelines (IPCC, 1996) describe two general tiers of methods for estimating EME. Tier 1 consists of a simple approach that determines EME by using default fixed ME factors published in the IPCC document (Appendix A) and livestock population data of the country from domestic or international sources. Tier 2 features a more complex method that requires country−specific data to calculate ME factors for different categories of animals according to the energy requirement equations (Appendix B):

$$EF_i = [GE_i \times Y_m \times 365]/[55.65 \text{ MJ/kg } CH_4] \qquad (1)$$

where

EF_i = emission factor for the *i* th animal category or subcategory (kg/head/year)

GE_i = gross energy intake of the *i* th animal category or subcategory (MJ/day) calculated from feed digestibility, animal body weight, milk production, weight gain, and other related animal performance parameters

Y_m = methane conversion rate (%) depending on country−specific feed quality.

The total emission of enteric methane (TE_{CH4}) is the sum of all animal categories, namely:

$$TE_{CH_4} \text{(Gg/year)} = \sum (EF_i \times N_i \times 10^{-6}) \qquad (2)$$

where

N_i = number or population of animals in the *i* th category

10^{-6} = conversion from kg to Gg.

IPCC Good Practices Guidance

The essence of the IPCC Good Practices Guidance is identification of the appropriate methods and detailed characterization of production conditions required to support emission estimation for each source category (IPCC, 2000). Compared with the Revised 1996 IPCC Guidelines, the IPCC Good Practices Guidance features the following improvements that make the Revised 1996 IPCC Guidelines equations applicable to a wider range of animal categories and management schemes. First, it classifies animal categories into minimum subcategories for each species. Second, it considers feeding situation of the animals, which is the most important factor affecting the animal production characteristics. Third, it provides enhanced characterization and equations to support the Tier 2 method for sheep (Appendix B). Fourth, it considers the net energy due to weight loss during extreme seasons.

ESTIMATION OF METHANE EMISSIONS (ME) IN CHINA

The Revised IPCC Tier 1 method was used to estimate ME from all animal species, including swine, camels, horses, mules, donkeys, dairy cattle, non−dairy cattle, buffalo, and sheep. In addition, the Revised IPCC Tier 2 method was used to estimate ME from dairy cattle, non−dairy cattle, buffalo, and sheep. Moreover, the IPCC Good Practices Guidance was used to estimate ME from dairy cattle and non−dairy cattle, integrating the effects of livestock classification and feeding schemes in different production areas, as described below. The primary reason for limiting estimation of ME from swine, horses, mules, and donkeys to the Tier 1 method was the absence of an energy requirement equation for these animals. In addition, contributions to overall ME by horses, mules, and donkeys are rather small, and treatment of ration (i.e., treated straw) is primarily applicable to cattle only.

Enhanced Classification of Livestock Species and Categories

The animal types and categories considered in this study represented different sizes, ages, and feeding systems typical of China, as documented in the China Animal Industry Yearbook (2001). In China, cattle are generally divided into yellow cattle, dairy cattle, and buffalo. Yellow cattle include the Chinese domestic yellow cattle, yaks, hybrid cattle, and crossbred beef cattle. Dairy cattle generally include imported high−yield breeds and their crosses. Buffalo are used primarily for draft power. Although the ME rate for the monogastric swine is much lower than that for ruminants, the large number of swine in China warrants its inclusion to improve the quality of the overall ME inventory estimation.

Classification of Animal Feeding Systems

For each type of cattle and sheep, the feeding systems were divided into two categories, grassland or pasture grazing (PG) system vs. non−pasture or crop production (CP) feeding system, based on the ration characteristics and management system.

Pasture grazing (PG) system: Pasturelands cross northern China, from Heilongjiang province in the east, across Inner Mongolia, and onto the Tibetan Plateau in the west. In 1998, the population of sheep and goats in PG system amounted to 74.5 million, or 27.7% of the total sheep and goat stock in China. Animals grazing on open pasture spend extra energy in acquiring feed, and consequently have lower productivity than their counterparts raised in non−pasture or CP areas where they are fed crop residues with or without grain supplement. Table 1 compares milk production and body weight gain of cattle under the two feeding systems.

Table 1. Comparison of animal characteristics in different feeding systems.

Animal Type	Region	Milk Production (kg/lactation)	Live Weight (kg)
Dairy cattle	Pasture grazing (PG)	3400	450
	Crop production (CP)	4300	500
Yellow cattle	Pasture grazing (PG)	702	300
	Crop production (CP)	1395	400

Data source: Xu (2000).

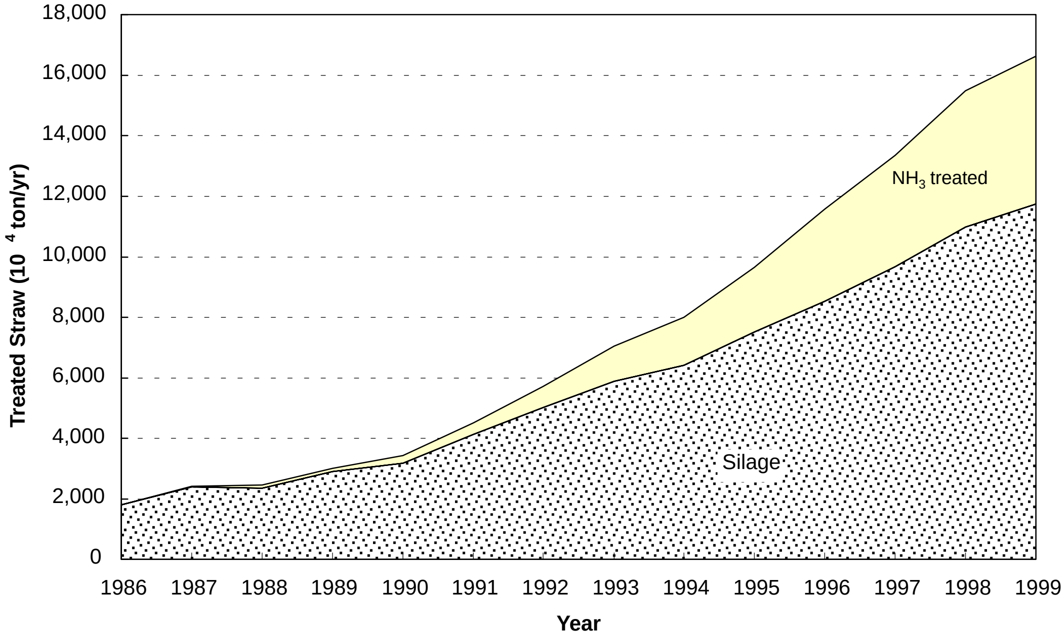

Figure 1. Amount of ammonia−treated straw and silage used for cattle feed in China during the period of 1986 to 1999.

Crop production (CP) feeding system: Unlike the herds in the pasture areas, cattle and sheep in smaller numbers are raised among millions of farming households in China. The feedstuff in the CP areas consists mostly of wheat straw, rice straw, and corn stalks. Historically, cattle in these areas have been raised for draft power as opposed to animal products. However, the rising demand for beef has led to a rapid increase in commercial beef cattle production. These animals are confined in barns or shelters, protected from adverse weather, and provided with improved rations for better production performance.

Incorporation of Improved Productivity Effect on Methane Emission

Due to the biochemical pathways through which animals produce methane, improved production efficiency, i.e., increase in meat or milk output per unit of feed/energy intake, will lead to a decrease in EME per unit animal product. Although animals of higher productivity usually emit more methane than their less productive counterparts on an individual basis, it would take fewer highly productive animals to produce the same product output. Consequently, the total ME from a smaller population of higher yield animals will be less than that from a larger population of lower yield animals. There has been a much greater acceptance of using treated straw to increase animal productivity and at the same time reduce EME in developing countries (Leng, 1991; ADB, 1999).

Since 1987, China has embarked on a national program to improve cattle productivity by using treated crop residues for cattle feed in CP areas. The treated crop residues are typically obtained through ammoniated treatment and silage process. Ammoniated treatment of crop residues involves addition of 2.5% to 3.5% (dry matter basis of the straw) of ammonium to the residues and fermentation for 2 to 8 weeks, depending on the ambient temperature. By 1998, treated straw for cattle feed had grown to about 155 million tons (fig. 1). Research data in China have shown that cattle had much higher digestibility with treated residues than with untreated residues (table 2). In the current ME estimation study, the effect of treated straw on ME factors was estimated by increasing digestibility of the ration and animal weight gain. The difference in total ME was assessed based on a daily consumption of 3.5 kg treated straw per cattle in the CP areas.

Data Sources for This Study

Data on national animal population were obtained from the China Agriculture Yearbook (1990−2001). To determine the population of animal species under different feeding systems for the period of 1990 to 1997, the percentage of animal population for each animal group under a feeding system in individual provinces for the year 1998 was multiplied by the 1990−1997 respective annual population of each province. The year 1998 was the only time when the animals were partitioned as percentages of the total population. Data on animal performance or production stage such as average live weight, weight gain, gestation and lactation period were obtained from published information (Chen, 1999) and through direct communications with experts at the China National Institute of Livestock Industry (Wu Keqian, personal communication, 2000−2004). Nutritional characteristics of the feed as recommended by Guo (1996) were used (table 2).

Results and Discussion

Emission Factors by Different IPCC Methods

Data in table 3 show variability in ME factors (MEFs) estimated with different IPCC methods. For cattle, including

Table 2. Digestibility and crude protein content of treated vs. untreated straw as cattle feed.

	% Crude Protein		% DM Digestibility	
Roughage	Untreated	Treated	Untreated	Treated
Wheat straw	2.2	7.64	39.7	50
Corn straw	3.7	8.72	42	60
Rice straw	3.86	7.84	24	48

Data source: Guo (1996).

Table 3. Methane emission factors of different animals estimated by different IPCC methods.

Animal Category	Subcategory	CH_4 Emission Factor (kg/head/year): Revised 1996 IPCC Guideline, Tier 1[a]	Revised 1996 IPCC Guideline, Tier 2	IPCC Good Practices: Crop Production (CP) Area, Untreated	Crop Production (CP) Area, Treated	Pasture Grazing (PG) Area, Untreated	Pasture Grazing (PG) Area, Treated
Dairy cattle	Mature female		78	79	79	72	
	Young (<1 year)	56	39	37	37	37	NA
	Other		52	53	57	52	
Yellow cattle	Mature female		64	69	51	70	
	Young (<1 year)	44	32	33	28	35	NA
	Other		66	78	54	94	
Buffalo	Mature female		63	65		65	
	Young (<1 year)	55	45	45	NA	45	NA
	Other		66	70		70	
Sheep	Mature female		14	13		9	
	Young (<1 year)	5	7	5	NA	4	NA
	Other		9	8		6	
Goat	Mature female		9	8		5	
	Young (<1 year)	5	4	4	NA	3	NA
	Other		5	4		4	
Swine	Not divided	1.0			NA		
Camel	Not divided	46			NA		
Horses	Not divided	18			NA		
Mules/donkeys	Not divided	10			NA		
Poultry	Not divided					Not estimated	

[a] Default emission factor for developing countries.

dairy cattle, yellow cattle, and buffalo, MEFs obtained with the IPCC Good Practices method were slightly greater than those obtained with the Tier 2 method when the estimation was based on the same animal characteristics in the CP area. However, MEFs for sheep and goats from the IPCC Good Practices method were smaller than those from the Tier 2 method. The different results for cattle and sheep arose from the reduced coefficients in net energy requirement for sheep maintenance adopted in the Good Practices Guideline vs. those used in the 1996 Revised Guidelines (Appendix B).

Impact of Treated Straw on Methane Emission (ME)

As it can be noticed from the data in table 3, use of treated straw or residues reduces MEFs for yellow cattle, a result of increased digestibility. Specifically, MEF reduction amounts to 26% for mature females, 16% for young (<1 year) animals, and 30% for others. The MEF reduction should be considered in determining ME inventory for countries where treated straw is routinely used.

The results of MEF reduction for yellow cattle differed from the literature report that treated straw could reduce ME per unit animal product but elevate MEF per animal (Leng, 1991). The slightly elevated MEF (57 vs. 53) for some dairy cattle (the "others" subcategory) fed treated straw presumably resulted from increased feed intake, which would in turn increase milk yield. Unfortunately, production data were not available to base the MEF on per unit milk output. As previously described, the highly productive dairy cows with increased feed intake (from treated ration) are expected to have a lower ME to milk output ratio.

Enteric Methane Emissions (EME) in China

The estimated EME for China during the period of 1990 to 1998 are summarized in table 4. The EME for 1996 (peak ME year of the studied period) were estimated to be 8,614; 11,039; 10,533 and 11,469 Gg, respectively, based on Tier 1, Tier 2, the IPCC Good Practices with or without the incorporation of treated straw effect. These EME values were 31%, 28%, 27%, and 20% higher than their respective values for 1990. The increase in ME over this time period was mostly attributed to the population increase in yellow cattle, dairy cattle and goats.

The emission data in table 4 indicate that adoption of feeding treated straw resulted in an ME reduction of 935.7 Gg/year or 14% and 1,253.5 Gg/year or 21%, respectively, for 1996 and 1998. This reduction was credited to yellow cattle fed with treated straw.

Table 4. Enteric methane emissions by all livestock species in China during the period of 1990 to 1998 based on different IPCC estimation methods (Tg CO_2 eq.).

Year or Year−to−Year Change	Estimation Methods: Revised 1996 IPCC Guideline, Tier 1	Revised 1996 IPCC Guideline, Tier 2	2000 IPCC Good Practices, Without Treated Straw	2000 IPCC Good Practices, With Treated Straw
1990	138	181	190	185
1991	140	183	192	184
1992	143	187	197	187
1993	149	195	205	193
1994	158	204	214	200
1995	170	219	227	211
1996	181	232	241	221
1997	157	201	208	186
1998	166	212	220	194
1990 to 1996 increase	31%	28%	27%	20%
1990 to 1998 increase	20%	17%	16%	5%

Table 5. Partition of enteric methane emissions by animal species in China in 1996.

CH_4 Emission	Animal Type						
	Yellow Cattle	Dairy Cattle	Buffalo	Sheep	Goats	Swine	Others
Gg	6,751	272	1,572	1,112	944	457	361
% of total EME	58.9%	2.4%	13.7%	9.7%	8.2%	4.0%	3.1%

Partition of Methane Emissions (ME) Among Different Animal Species

The magnitude and partitioning of ME by animal species for 1996 are presented in table 5. As can be seen, yellow cattle were the largest contributor to EME in China, accounting for nearly 60% of the total EME. Buffalo and sheep were the second and third largest source, accounting for about 14% and 10% of the total EME, respectively. Emissions by dairy cattle account for less than 3% of the overall EME. However, with the rising demand for dairy products in China, the importance of ME from dairy cattle is expected to increase.

In the meantime, the share of ME from swine production remained relatively constant from 1990 to 1998. Accounting for about 4% of the national inventory, ME from swine is greater than that from dairy cattle, even though the monogastric swine have a very low MEF.

Challenges Inherent to Estimating Enteric Methane Emissions

The inventory of EME is beset with many uncertainties in the IPCC GHG inventory activities. The primary factor contributing to the uncertainty in ME estimation in China is the lack of information on the animal characteristics and the methane conversion rate of China−specific animal production systems. Specifically, there is a large uncertainty in feed intake and feed digestibility. Generally, data on average daily feed intake are unavailable. Feed intake was estimated based on the energy requirement equations. Generally, feed supply does not meet the energy requirements of the animals in China because of specific livestock management schemes practiced by individual farm families. Hence, feed intake could be overestimated. In addition, the two feeding managements categorized in this estimation are by no means inclusive of all feeding systems in China. Feed digestibility of different systems in different regions may vary as much as 20% to 30%. Moreover, the methane conversion rates for all animal groups were set to the default IPCC factors, even though country−specific factors may differ considerably. Given the varying animal management practices and continuous improvement in animal productivity in China, use of constant emission factors over time may yield large uncertainty.

Conclusions

Enteric methane emissions (EME) in China were evaluated with different IPCC estimation methods and under different livestock production conditions. Based on the methods of the Revised 1996 IPCC Guidelines (Tier 1 and Tier 2) and the IPCC Good Practices Guidance (with or without incorporation of treated straw effect), EME in China for 1996 were determined to be 8,614; 11,039; 10,533; and 11,469 Gg, respectively, a 33% difference between estimations using Tier 1 and Good Practices without straw treatment. The EME values for 1996 were 31%, 28%, 27%, and 20% higher than their respective values for 1990, the base year for evaluating subsequent EME changes. Yellow cattle contribute more than 50% of the EME in China.

Yellow cattle fed treated straw had a 26% to 30% lower emission factor than those fed untreated straw. Adoption of feeding cattle treated straw was projected to have reduced methane emission from yellow cattle in China by 935.7 Gg in 1996 and by 1,253.5 Gg in 1998.

Despite the much smaller methane emission factor for swine than for cattle, the large swine population makes its methane emission twice that from dairy cattle in China; hence it should be included in the national methane emission inventory.

Recommendations for Future Inventory Updating

Estimation of EME remains an area of large uncertainty, and further improvements are needed. The following measures are proposed for improving the quality of future EME estimation:

- Adjust emission factors to reflect the changing technologies in livestock production systems.
- Incorporate the effects of animal population composition, animal performance, and feed quality in different predominant feeding systems.
- Conduct adequate field experiments to quantify methane emission factors for major contributing species, such as yellow cattle and buffalo.
- Consider changing the default emission factor for dairy cattle in China from 56 kg/head/year to 60−70 kg/head/year because the dairy cattle documented in China Animal Industry Yearbook and used in ME estimation represent the improved breeds with high milk yield of 4,000 to 5,000 kg/lactation, as compared with 1650 kg/lactation assumed in the default emission factor.
- Include methane emission from swine operations in the methane emission inventory for countries with large population of swine.

Acknowledgements

The authors wish to thank Prof. Shuzo Nishioka of the Institute for Global Environmental Strategies (IGES), Dr. Hideyuki Shimizu of the National Institute for Environmental Science (NIES), Dr. Hiraishi and Dr. Kiyoto Tanabe of the IPCC Technical Support Unit (TSU) for their review and constructive suggestions. The authors are also grateful to Ms. Yue Li, Mr. Shangzhong Xu, and Mr. Keqian Wu of CAAS and Mr. Wei Kang of the Chinese Ministry of Agriculture for their assistance in collecting the related data on cattle characteristics in China.

References

ADB. 1999. *Asian Least−Cost Greenhouse Gas Abatement Strategies − People's Republic of China*, 115−119. Manila, Philippines: Asian Development Bank.

Chen Y. 1999. *Modern Beef Cattle Production* (in Chinese). Beijing, China: China Agriculture Press.

China Animal Industry Yearbook. 2001. ISSN 1009−7996. Beijing, China: China Agriculture Press.

China Agriculture Yearbook. 1990−2001. ISSN 1009−6558. Beijing, China: China Agriculture Press.

Guo, T. 1996. *Livestock Production Based on Straw*. Shanghai, China: Shanghai Science and Technology Press.

IPCC 1996. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*. Bracknell, U.K.: IPCC WGI Technical Support Unit.

IPCC 2000. *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, Chapter 4. Kanagawa, Japan: IPCC National Greenhouse Gas Inventories Program Technical Support Unit.

Leng, R. A. 1991. *Improving Ruminant Production and Reducing Methane Emissions from Ruminants by Strategic Supplementation*. Washington, D.C.: EPA.

RS−CCCCS (Research Team of China Climate Change Country Study). 1999. *China Climate Change: Country Study*. Beijing, China: Tsinghua University Press.

Xu, S. 2000. *Report on National "Tenth−Five Year" Research Project on Cattle Breeding in China*. Beijing, China: China National Institute of Livestock Industry.

APPENDIX A: DEFAULT FIXED EMISSION FACTORS ADOPTED BY IPCC (IPCC, 1996)

Table 4−3. Enteric fermentation emission factors (kg per head per year).

Livestock	Developed Countries	Developing Countries
Buffalo	55	55
Sheep	8	5
Goats	5	5
Camels	46	46
Horses	18	18
Mules and asses	10	10
Swine	1.5	1.0
Poultry	Not estimated	Not estimated

All estimates are ±20%

Table 4−4. Enteric fermentation emission factors for cattle.

	Emission Factor (kg/head/year)		Avg. Milk Production of Dairy Cows (kg/head/year)
Region	Dairy	Non−dairy	
North America	118	47	6,700
Western Europe	100	48	4,200
Eastern Europe	81	56	2,550
Oceania	68	53	1,700
Latin America	57	49	800
Asia	56	44	1,650
Africa and Middle East	36	32	475
Indian subcontinent	46	25	900

APPENDIX B: METABOLIC FUNCTIONS USED TO ESTIMATE FEED ENERGY INTAKE FOR ANIMALS IN IPCC D OCUMENTS (IPCC, 1996, 2000)

Energy Distribution (MJ/day)	IPCC Good Practices	1996 IPCC Guideline
Net energy for maintenance (NE_m)	$NE_m = Cf_i \times BW^{0.75}$	$NE_m = 0.322 \times BW^{0.75}$ (for cattle) $NE_m = 0.335 \times BW^{0.75}$ (for dairy cows)
Net energy for activity (NE_a)	$NE_a = C_a \times NE_m$ (for cattle and buffalo) $NE_a = C_a \times BW$ (for sheep)	$NE_{feed} = 0$ (for animals confined in pens) NE_{feed} = 17% of NE_m (for animals grazing good quality pasture) NE_{feed} = 37% of NE_m (for animals grazing over very large areas)
Net energy for growth (NE_g)	$NE_g = 4.18 \times \{0.0635 \times [0.891 \times BW \times 0.96 \times 478/(C \times MW)]^{0.75} \times (WG \times 0.92)^{1.097}\}$ (for cattle and buffalo) $NE_g = \{WG_{lamb} \times [a + 0.5b\,(BW_i + BW_f)]\}/365$ (for sheep)	$NE_g = 4.18 \times \{(0.035\, BW^{0.75} \times WG^{1.119}) + WG\}$
Energy in weight loss ($NE_{mobilized}$)	$NE_{mobilized} = 19.7 \times WL$ (for lactating dairy cows) $NE_{mobilized} = NE_g \times (-0.8)$ (for buffalo and other cattle)	N/A
Net energy for lactation (NE_l)	NE_l = kg of milk per day × (1.47 + 0.40 × % fat content) (for cattle and buffalo) NE_l = kg of milk per day × EV_{milk} (for sheep, milk production known) $NE_l = [(5 \times WG_{lamb})/365] \times EV_{milk}$ (for sheep, milk production unknown) where EV_{milk} = 4.6 MJ/kg	NE_l = kg of milk/day × (1.47 + 0.40 × fat %)
Net energy for work (NE_w)	$NE_w = 0.10 \times NE_m$ × hours of work per day	$NE_{draft} = 0.10 \times NE_m$ × hours of work per day
Net energy required for sheep to produce a year of wool (NE_{wool})	$NE_{wool} = (EV_{wool}$ × annual wool production per sheep, kg/year)/(365)	N/A
Energy required for pregnancy (NE_p)	$NE_p = C_{pregnancy} \times NE_m$ (for cattle, buffalo, and sheep) where $C_{pregnancy}$ = pregnancy coefficient	$NE_{pregnancy}$ (MJ/281−day period) = 28 × calf birth weight in kg Calf birth weight (kg) = $0.266 \times (\text{cow BW})^{0.79}$
Ratio of net energy for maintenance to digestible energy (NE_{ma}/DE)	$NE_{ma}/DE = 1.123 - (4.092 \times 10^{-3} \times DE) + [1.126 \times 10^{-5} \times (DE)^2] - (25.4/DE)$ where digestible energy is expressed as a percentage of gross energy	$NE/DE = 1.123 - (4.092 \times 10^{-3} \times DE\%) + (1.126 \times 10^{-5} \times (DE\%)^2) - 25.4/DE\%$ (for digestibility > 65%) $NE/DE = 0.298 + (0.00335 \times DE\%$ (for digestibility < 65%)

(continued below)

Energy Distribution (MJ/day)	IPCC Good Practices	1996 IPCC Guideline
Ratio of net energy for growth to digestible energy (NE_{ga}/DE)	$NE_{ga}/DE = 1.164 - (5.160 \times 10^{-3} \times DE) + (1.308 \times 10^{-5} \times (DE)^2) - (37.4/DE)$	$NE_g/DE = 1.164 - (5.160 \times 10^{-3} \times DE\%) + (1.308 \times 10^{-5} \times (DE\%)^2) - 37.4/DE\%$ (for digestibility > 65%) $NE_g/DE = -0.036 + (0.00535 \times DE\%)$ (for digestibility < 65%)
Gross energy (GE)	$GE = \{[(NE_m + NE_{mobilized} + NE_a + NE_l + NE_w + NE_p)/(NE_{ma}/DE)] + [(NE_g + E_{wool})/(NE_{ga}/DE)]\}/(DE/100)$	$GE = [(NE_m + NE_{feed} + NE_l + NE_{draft} + NE_{pregnancy}) \times (100/DE\%)]/[(NE/DE) + NE_g/ (NE_g/DE)]$

BW = live body weight (kg); Cf_i = 0.322, 0.335, 0.236, and 0.217 for non−lactating cattle/buffalo, lactating cattle/buffalo, sheep (lamb to 1 year), and sheep older than 1 year, respectively.

C_a = 0, 0.17, and 0.36 for cattle and buffalo confined, confined in areas with sufficient forage, and grazing in open range land or hilly terrain, respectively.

C_a = 0.0090, 0.0107, 0.024, and 0.0067 for housed ewes, sheep grazing flat pasture and walking up to 1000 m per day, sheep grazing hilly pasture and walking up to 5000 meters per day, and housed fattening lambs, respectively.

For cattle and buffalo: C = 0.8 for females, 1.0 for castrates, and 1.2 for bulls; MW = mature body weight (kg); WG = daily weight gain (kg/day).

For sheep: *a* = 2.5, 4.4, and 2.1 for intact males, castrates, and females, respectively; *b* = 0.35, 0.32, and 0.45 for intact males, castrates, and females, respectively; WG_{lamb} = weight gain (kg); BW_i = body weight at weaning (kg); and BW_f = body weight at 1 year old or at slaughter (kg).

WL = daily weight loss (kg/day); EV_{milk} = energy value for milk; and EV_{wool} = energy value of each kg of wool produced (MJ/kg).

$C_{pregnancy}$ = 0.10 for cattle and buffalo; and 0.077, 0.126, and 0.150 for sheep having single birth, double birth, and triple birth or more, respectively.