CHAPTER 4
AGRICULTURE

4. AGRICULTURE

4.1 Overview

Agricultural activities contribute directly to emissions of greenhouse gases through a variety of different processes. This chapter discusses four greenhouse gas-emitting activities:

- **CH_4 and N_2O emissions from domestic livestock (enteric fermentation and manure management)**

  – ***CH_4 emissions from enteric fermentation in domestic livestock***
  Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the bloodstream. Both ruminant animals (e.g., cattle, sheep) and some non-ruminant animals (e.g., pigs, horses) produce CH_4, although ruminants are the largest source since they are able to digest cellulose, a type of carbohydrate, due to the presence of specific micro-organisms in their digestive tracts. The amount of CH_4 that is released depends on the type, age, and weight of the animal, the quality and quantity of the feed, and the energy expenditure of the animal.

  – ***CH_4 emissions from manure management***
  CH_4 is produced from the decomposition of manure under anaerobic conditions. These conditions often occur when large numbers of animals are managed in a confined area (e.g., dairy farms, beef feedlots, and swine and poultry farms), where manure is typically stored in large piles or disposed of in lagoons.

  – ***N_2O emissions from manure management***
  During storage of manure, some manure nitrogen is converted to N_2O. Emissions of N_2O related to manure handling before the manure is added to soils are included in this source category. (Manure-related N_2O emissions from soils are considered agricultural soil emissions).

- **CH_4 emissions from rice cultivation**

  Anaerobic decomposition of organic material in flooded rice fields produces methane, which escapes to the atmosphere primarily by transport through the rice plants. The amount emitted is believed to be a function of rice species, number and duration of harvests, soil type and temperature, irrigation practices, and fertiliser use. The seasonally integrated CH_4 flux depends upon the input of organic carbon, water regimes, time and duration of drainage, soil type etc.

- **CH_4, CO, N_2O, and NO_X emissions from agricultural burning (savanna and agricultural burning)**

  – ***CH_4, CO, N_2O, and NO_X emissions from the prescribed burning of savannas***
  The burning of savannas – areas in tropical and subtropical formations with continuous grass coverage – results in the instantaneous emissions of carbon

dioxide, but because the vegetation regrows between burning cycles, the carbon dioxide released into the atmosphere is reabsorbed during the next vegetation growth period. Net CO_2 emissions are therefore assumed to be zero. However, savanna burning also releases gases other than CO_2, including methane, carbon monoxide, nitrous oxide and oxides of nitrogen. Unlike CO_2 emissions, these are net emissions.

– ***CH_4, CO, N_2O, and NO_X emissions from the burning of agricultural residues***

The burning of crop residues is not thought to be a net source of carbon dioxide because the carbon released to the atmosphere is reabsorbed during the next growing season. However, this burning is a significant source of emissions of methane, carbon monoxide, nitrous oxide, and nitrogen oxides. It is important to note that some crop residues are removed from the fields and burned as a source of energy, especially in developing countries. Non-CO_2 emissions from this type of burning are dealt with in the *Energy* module of this manual. Crop residue burning must be properly allocated to these two components in order to avoid double counting.

- **CH_4, CO_2, and N_2O emissions from agricultural soils**

Emissions of N_2O from agricultural soils are primarily due to the microbial processes of nitrification and denitrification in the soil. Three types of emission can be distinguished: direct soils emissions, direct soil emissions of N_2O from animal production (including stable emissions to be reported under Manure Management) and indirect emissions. Increases in the amount of nitrogen added to the soil generally result in higher N_2O emissions (Bouwman, 1990). Direct soil emissions may result from the following nitrogen input to soils: (1) synthetic fertilisers, (2) nitrogen from animal waste, (3) biological nitrogen fixation, (4) reutilised nitrogen from crop residues, and (5) sewage sludge application. In addition, cultivation of organic soils may increase soil organic matter mineralisation and, in effect, N_2O emissions. Direct soil emissions of N_2O from animal production include those induced by grazing animals. Emissions from other animal waste management systems are reported under "Manure Management''. Indirect N_2O emissions take place after nitrogen is lost from the field as NO_X, NH_3 or after leaching or runoff. Agricultural soils may also emit or remove CO_2 and/or CH_4. For example, peat compost used as a soil amendment in agriculture and gardening may result in CO_2 emissions or removals. Carbon emissions from organic, mineral and limed soils are discussed in Chapter 5.

4.2 Methane And Nitrous Oxide Emissions From Domestic Livestock Enteric Fermentation And Manure Management

4.2.1 Overview of Methane and Nitrous Oxide Emissions from Livestock

This section covers methane and nitrous oxide emissions from enteric fermentation and the management of manure from domestic livestock. Cattle are the most important source of methane from enteric fermentation in most countries because of their high numbers, large size, and ruminant digestive system. Methane emissions from manure management are usually smaller than enteric fermentation emissions, and are principally associated with confined animal management facilities where manure is handled as a liquid. This section presents a brief overview of the key factors affecting methane and nitrous oxide emissions from these sources. The methods for estimating methane emissions are then presented.[1] The method for estimating nitrous oxide emissions from manure management is presented in Section 4.5.3.

Enteric Fermentation

Methane is produced during the normal digestive processes of animals. The amount of methane produced and excreted by an individual animal is dependent primarily on the following:

- **Digestive System**
  The type of digestive system has a significant influence on the rate of methane emission. *Ruminant animals* have the highest emissions because a significant amount of methane-producing fermentation occurs within the rumen. The main ruminant animals are cattle, buffalo, goats, sheep and camels. *Pseudo-ruminant animals* (horses, mules, asses) and *monogastric animals* (swine) have relatively lower methane emissions because much less methane-producing fermentation takes place in their digestive systems.

- **Feed Intake**
  Methane is produced by the fermentation of feed within the animal's digestive system. Generally, the higher the feed intake, the higher the methane emission. Feed intake is positively related to animal size, growth rate, and production (e.g., milk production, wool growth, or pregnancy).

The amount of methane emitted by a population of animals is calculated by multiplying the emission rate per animal by the number of animals. To reflect the variation in emission rates among animal types, the population of animals is divided into subgroups, and an emission rate per animal is estimated for each subgroup. Types of population subgroup are recommended in the method[2].

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[1] All GHG emissions from the burning of animal waste are estimated in Section 1.4; Greenhouse Gas Emissions from Burning Traditional Biomass Fuels. CO_2 from the burning of animal waste is part of a closed cycle and is not counted as net CO_2.

[2] Countries are encouraged to carry out emissions inventory calculations at a finer level of detail if possible. Many countries have available more detailed information than

Human management of wildlife can affect the total number of animals and therefore their emissions, though the associated emissions are believed to be small. The key issue is distinguishing those emissions resulting from human interventions from those emissions that would have occurred naturally. No methodology for estimating these emissions is presented here, though they may be estimated if national experts can fully document their approach, including all assumptions and methods. If these emissions are estimated, they should be reported in the "Other" subcategories of the Enteric Fermentation and Animal Wastes Tables (4 A & B) of *Volume 1: Reporting Instructions*.

Manure Management

Livestock manure is principally composed of organic material. When this organic material decomposes in an anaerobic environment (i.e., in the absence of oxygen), methanogenic bacteria, as part of an interrelated population of micro-organisms, produce methane.

The principal factors affecting methane emission from animal manure are the amount of manure produced and the portion of the manure that decomposes anaerobically. The amount of manure that is produced is dependent on the amount produced per animal and the number of animals. The portion of the manure that decomposes anaerobically depends on how the manure is managed. When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it tends to decompose anaerobically and produce a significant quantity of methane. When manure is handled as a solid (e.g., in stacks or pits) or when it is deposited on pastures and rangelands, it tends to decompose aerobically and little or no methane is produced.

To estimate methane emission, the animal population must be divided into subgroups to reflect the varying amounts of manure produced per animal, and the manner in which the manure is handled. Population subgroups are recommended in the method.

Nitrous oxide is formed when manure nitrogen is nitrified or denitrified. The amount of N_2O released depends on the system and duration of waste management. Emissions of N_2O taking place during storage or handling of manure (i.e., before the manure is added to soils) are reported under " Manure Management". Manure-induced N_2O emissions from soils are considered soil emissions (See Section 4.5 of this Reference Manual).

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was used in constructing default values here. Countries may wish to calculate emissions estimates at a finer level of detail by subcategory – further disaggregating recommended activity categories and subcategories – or they may choose to subdivide the categories on some other basis which they feel is appropriate to their particular national circumstances. Working at finer levels of disaggregation does not change the basic nature of the calculations. Once emissions have been calculated at whatever is determined by the national experts to be the most appropriate level of detail, results should also be aggregated up to the minimum standard level of information requested in the IPCC proposed methodology. This will allow for comparability of results among all participating countries. The data and assumptions used for finer levels of detail should also be reported to the IPCC to ensure transparency and replicability of methods. *Volume 1: Reporting Instructions* discusses these issues in more detail.

Box 1

HUMAN WASTE USED AS FERTILISER

Human waste is sometimes used as fertiliser, and can result in emissions or removals of CH_4, N_2O or CO_2. At present, no methodology can be recommended for estimating CH_4 and CO_2 emissions. N_2O emissions from Human waste are described in Chapters 4 & 6. The development of a methodology specifically for this source has been identified as an area for future work. Countries are nevertheless encouraged to estimate emissions from this source if they are able to do so. CH_4 emissions from this source can be estimated in one of at least two ways:

- Emissions from human waste used as fertiliser may be estimated in the present section by adapting the methodology for estimating emissions from livestock manure to use the data provided below. In this case, the estimate should be reported in the "Other" line in Tables 4 A & B in *Volume 1: Reporting Instructions*.

  Bhattacharya et al. (1993) has reported these characteristics of human waste:

Dry waste per day	=	0.107 kg/head/day
Fractional carbon content	=	0.375

  And Thomas (1994, in press) reports the following values:

Volatile solid production	=	0.06 kg/head/day
Dry matter production	=	0.09 kg/head/day
Fractional carbon content	=	4.46% of dry matter

- These emissions can also be estimated using the methodology for sewage treatment in the Waste section. In this case, the emissions should then be treated as wastewater disposed of in aerobic (shallow) ponds, and should be reported in Table 6 B.

In any case, care should be taken to avoid double counting emissions from this source.

4.2.2 Inventory Method for Methane – Overview

The method for estimating methane emission from enteric fermentation and manure management requires three basic steps:

Step 1: Divide the livestock population into subgroups and characterise each subgroup. It is recommended that national experts use three year averages of activity data if available. This is to help prevent bias in the event that the base year of the inventory was an exceptional year not representative of the country's normal activity level.

Step 2: Estimate emission factors for each subgroup in terms of kilograms of methane per animal per year – separate emission factors are required for enteric fermentation and manure.

Step 3: Multiply the subgroup emission factors by the subgroup populations to estimate subgroup emission, and sum across the subgroups to estimate total emission.

These three steps can be performed at varying levels of detail and complexity. This chapter presents the following two approaches:

- **Tier 1**
  A simplified approach that relies on default emission factors drawn from previous studies. The Tier 1 approach is likely to be sufficient for most animal types in most countries.

- **Tier 2**
  A more complex approach that requires country-specific information on livestock characteristics and manure management practices. The Tier 2 approach is recommended when the data used to develop the default values do not correspond well with the country's livestock and manure management conditions. Because cattle characteristics vary significantly by country, it is recommended that countries with large cattle populations consider using the Tier 2 approach for estimating methane emissions from cattle and cattle manure. Similarly, because buffalo and swine manure management practices vary significantly by country, it is recommended that countries with large buffalo and swine populations consider using the Tier 2 approach for estimating methane emissions for manure from these animals.

Some countries for which livestock emissions are particularly important may wish to go beyond the Tier 2 method and incorporate additional country-specific information in their estimates. Although countries are encouraged to go beyond the Tier 2 approach presented below when data are available, these more complex analyses are only briefly discussed here. Table 4-1 summarises the recommended approaches for the livestock emissions included in this inventory.

TABLE 4-1
DOMESTIC LIVESTOCK INCLUDED IN THE METHODS

Livestock	Recommended Emissions Inventory Methods	
	Enteric Fermentation	Manure Management
Dairy Cattle	Tier 2[a]	Tier 2[a]
Non-dairy Cattle	Tier 2[a]	Tier 2[a]
Buffalo	Tier 1	Tier 2[a]
Sheep	Tier 1	Tier 1
Goats	Tier 1	Tier 1
Camels	Tier 1	Tier 1
Horses	Tier 1	Tier 1
Mules and Asses	Tier 1	Tier 1
Swine	Tier 1	Tier 2[a]
Poultry	(Not Estimated)	Tier 1

[a] The Tier 2 approach is recommended for countries with large livestock populations. Implementing the Tier 2 approach for additional livestock subgroups may be desirable when the subgroup emissions are a large portion of total methane emissions for the country.

4.2.3 Inventory Method for Methane – Tier 1 Approach

This Tier 1 method is simplified so that only readily-available animal population data are needed to estimate emissions. Default emission factors are presented for each of the recommended population subgroups. Each step is discussed in turn.

TIER 1: STEP 1 – LIVESTOCK POPULATIONS

The *average annual population* of livestock is required for each of the livestock categories listed in Table 4-1. In some cases the population fluctuates during the year. For example, a census done before calving will give a much smaller number than a census done after calving. A representative average of the population is therefore needed. In the case of poultry and swine, the number of animals *produced* each year exceeds the annual average population because the animals live for less than 12 months. The population data can be obtained from the FAO Production Yearbook (FAO, 1990) or similar country-specific livestock census reports.

The dairy cattle population is estimated separately from other cattle (see Table 4-2). Dairy cattle are defined in this method as mature cows that are producing milk in commercial quantities for human consumption. This definition corresponds to the dairy cow population reported in the FAO Production Yearbook.

In some countries the dairy cattle population is comprised of two well-defined segments: high-producing "improved" breeds in commercial operations; and low-producing cows managed with traditional methods. These two segments can be combined, or can be evaluated separately by defining two dairy cattle categories. However, the dairy cattle category does not include cows kept principally to produce calves or to provide draft power. Low productivity multi-purpose cows should be considered as non-dairy cattle.

Data on the average milk production of dairy cattle is also required. These data are expressed in terms of kilograms of whole fresh milk produced per year per dairy cow, and can be obtained from the FAO Production Yearbook or similar country-specific reports. If two or more dairy cattle categories are defined, the average milk production per cow is required for each category.

Finally, the livestock populations must be described in terms of warm, temperate, or cool climates for purposes of estimating emissions from livestock manure. Data on the annual average temperature of the regions where livestock are managed should be used as follows:

- Areas with annual average temperatures less than 15°C are defined as cool.
- Areas with annual average temperatures from 15°C to 25°C inclusive are defined as temperate.
- Areas with annual average temperatures greater than 25°C are defined as warm.

For each livestock population, the fraction in each climate should be estimated. These data can be developed from country-specific climate maps and livestock census reports. To the extent possible, the temperature data should reflect the locations where the livestock are managed. If necessary, data from nearby cities can be used. Table 4-2 summarises the animal population data that must be collected in Step 1.

TABLE 4-2

ANIMAL POPULATION DATA COLLECTED IN TIER 1 STEP 1

Livestock	Data Collected				
	Population (# head)	Milk Production (kg/head/yr)	Population By Climate (%)		
			Cool	Temperate	Warm
Dairy Cattle	Average Annual Population	Milk Production per Head	% Cool	% Temp.	% Warm
Non-dairy Cattle	Average Annual Population	Not Applicable (NA)	% Cool	% Temp.	% Warm
Buffalo	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Sheep	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Goats	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Camels	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Horses	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Mules and Asses	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Swine	Average Annual Population	(NA)	% Cool	% Temp.	% Warm
Poultry	Average Annual Population	(NA)	% Cool	% Temp.	% Warm

Data can be obtained from the FAO Production Yearbook and country-specific livestock census reports. Climates are defined in terms of average annual temperature as follows: Cool = less than 15°C; Temperate = from 15°C to 25°C inclusive; Warm = greater than 25°C.

TIER 1: STEP 2 – EMISSION FACTORS

The purpose of this step is to select emission factors that are most appropriate for the country's livestock characteristics. Default emission factors for enteric fermentation and manure management have been drawn from previous studies, and are organised by region for ease of use. The basis for the emission factors, described more fully under Tier 2, includes the following:

- *Enteric Fermentation:*
  - *Feed Intake*: Feed intake is estimated based on the energy intake required by the animal for maintenance (the basic metabolic functions needed to stay alive) and production (growth, lactation, work, and gestation). The livestock characteristics required to estimate feed intake are taken from regional and country-specific studies and include: population structure (portion of adults and young), weight, rate of weight gain, amount of work performed, portion of cows giving birth each year, and milk production per cow.

– *Conversion of Feed Energy to Methane*: The rate at which feed energy is converted to methane is estimated based on the quality of the feed consumed – low quality feed has a slightly higher methane conversion rate. Feed quality is assessed in terms of digestibility on a regional basis.

- *Manure Management:*

  – *Manure Production*: Manure production is estimated based on feed intake and digestibility, both of which are used to develop the enteric fermentation emission factors.

  – *Methane Producing Potential*: Methane producing potential (referred to as B_o) is the maximum amount of methane that can be produced from a given quantity of manure. The methane producing potential varies by animal type and the quality of the feed consumed. Reported measurements for selected animals are used.

  – *Methane Conversion Factor (MCF)*: The MCF defines the portion of the methane producing potential (B_o) that is achieved. The MCF varies with the manner in which the manure is managed and the climate, and can theoretically range from 0 to 100 per cent. Manure managed as a liquid under hot conditions promotes methane formation and emissions. These manure management conditions have high MCFs, of 65 to 90 per cent. Manure managed as dry material in cold climates does not readily produce methane, and consequently has an MCF of about 1 per cent. Laboratory measurements were used to estimate MCFs for the major manure management techniques.

  – *Manure Management Practices*: Regional assessments of manure management practices are used to estimate the portion of the manure that is handled with each manure management technique.

The data used to estimate the default emission factors for enteric fermentation and manure management are presented in Appendix A and Appendix B respectively, at the end of this section.

Table 4-3 shows the enteric fermentation emission factors for each of the animal types except cattle. As shown in the table, emission factors for sheep and swine vary for developed and developing countries. The differences in the emission factors are driven by differences in feed intake and feed characteristic assumptions (see Appendix A). Although point estimates are given for the emission factors, an uncertainty of about $\pm$20 per cent exists due to variations in animal management and feeding. Deviations from the emission factors can be larger than 20 per cent under specialised feeding or management conditions.

Table 4-4 presents the enteric fermentation emission factors for cattle. A range of emission factors is shown for typical regional conditions. As shown in the table, the emission factors vary by over a factor of four on a per head basis.

While the default emission factors shown in Table 4-4 are broadly representative of the emission rates within each of the regions described, emission factors vary among countries within regions. Also, as with the emission factors shown in Table 4-3, an uncertainty of about $\pm$20 per cent exists due to variations in animal management and feeding. Animal size and milk production are important determinants of emission rates for dairy cows. Relatively smaller dairy cows with low levels of production are found in Asia, Africa, and the Indian subcontinent. Relatively larger dairy cows with high levels of production are found in North America and Western Europe.

TABLE 4-3
ENTERIC FERMENTATION EMISSION FACTORS
(KG PER HEAD PER YR)

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 %

Sources: Emission factors for buffalo and camels from Gibbs and Johnson (1993). Emission factors for other livestock from Crutzen et al. (1986).

Animal size and population structure are important determinants of emission rates for non-dairy cattle. Relatively smaller non-dairy cattle are found in Asia, Africa, and the Indian subcontinent. Also, many of the non-dairy cattle in these regions are young. Non-dairy cattle in North America, Western Europe and Oceania are larger, and young cattle constitute a smaller portion of the population[3].

Select emission factors from Tables 4-3 and 4-4 by identifying the region most applicable to the country being evaluated. The data collected on the average annual milk production by dairy cows should be used to help select a dairy cow emission factor. If necessary, interpolate between dairy cow emission factors shown in the table using the data collected on average annual milk production per head.

Table 4-5 shows the default manure management emission factors for each animal type except cattle, buffalo, and swine. Separate emission factors are shown for developed and developing countries, reflecting the general differences in feed intake and feed characteristics of the animals in the two regions. These emission factors reflect the fact that virtually all the manure from these animals is managed in dry manure management systems, including pastures and ranges, drylots, and daily spreading on fields (Woodbury and Hashimoto, 1993).

[3] For each animal category, it is important to use the average weight of the animal during the year for estimating emissions. Because the weights of mature animals may fluctuate seasonally, a representative weight should be selected that considers conditions throughout the year. For growing animals, the average weight is generally less than the final (or end) weight of the animal at the end of the year. Growth rate statistics should be used to estimate the average weight during the year for purposes of estimating emissions.

TABLE 4-4
ENTERIC FERMENTATION EMISSION FACTORS FOR CATTLE

Regional Characteristics	Cattle Type	Emission Factor (kg/head/yr)	Comments
***North America*: Highly productive commercialised dairy sector feeding high quality forage and grain. Separate beef cow herd, primarily grazing with feed supplements seasonally. Fast-growing beef steers/heifers finished in feedlots on grain. Dairy cows are a small part of the population.	Dairy	118	Average milk production of 6,700 kg/head/yr
	Non-dairy	47	Includes beef cows, bulls, calves, growing steers/heifers, and feedlot cattle.
***Western Europe*: Highly productive commercialised dairy sector feeding high quality forage and grain. Dairy cows also used for beef calf production. Very small dedicated beef cow herd. Minor amount of feedlot feeding with grains.	Dairy	100	Average milk production of 4,200 kg/head/yr.
	Non-dairy	48	Includes bulls, calves, and growing steers/heifers.
***Eastern Europe*: Commercialised dairy sector feeding mostly forages. Separate beef cow herd, primarily grazing. Minor amount of feedlot feeding with grains.	Dairy	81	Average milk production of 2,550 kg/head/yr.
	Non-dairy	56	Includes beef cows, bulls, and young.
***Oceania*: Commercialised dairy sector based on grazing. Separate beef cow herd, primarily grazing rangelands of widely varying quality. Growing amount of feedlot feeding with grains. Dairy cows are a small part of the population.	Dairy	68	Average milk production of 1,700 kg/head/yr.
	Non-dairy	53	Includes beef cows, bulls, and young.
***Latin America*: Commercialised dairy sector based on grazing. Separate beef cow herd grazing pastures and rangelands. Minor amount of feedlot feeding with grains. Growing non-dairy cattle comprise a large portion of the population.	Dairy	57	Average milk production of 800 kg/head/yr.
	Non-dairy	49	Includes beef cows, bulls, and young.
***Asia*: Small commercialised dairy sector. Most cattle are multi-purpose, providing draft power and some milk within farming regions. Small grazing population. Cattle of all types are smaller than those found in most other regions.	Dairy	56	Average milk production of 1,650 kg/head/yr.
	Non-dairy	44	Includes multi-purpose cows, bulls, and young
***Africa and Middle East*: Commercialised dairy sector based on grazing with low production per cow. Most cattle are multi-purpose, providing draft power and some milk within farming regions. Some cattle graze over very large areas. Cattle of all types are smaller than those found in most other regions.	Dairy	36	Average milk production of 475 kg/head/yr.
	Non-dairy	32	Includes multi-purpose cows, bulls, and young
***Indian Subcontinent*: Commercialised dairy sector based on crop by-product feeding with low production per cow. Most bullocks provide draft power and cows provide some milk in farming regions. Small grazing population. Cattle in this region are the smallest compared to cattle found in all other regions.	Dairy	46	Average milk production of 900 kg/head/yr.
	Non-dairy	25	Includes cows, bulls, and young. Young comprise a large portion of the population

TABLE 4-5
MANURE MANAGEMENT EMISSION FACTORS
(KG PER HEAD PER YR)

Livestock	Developed Countries			Developing Countries		
	Cool	Temp.[a]	Warm	Cool	Temp.[a]	Warm
Sheep	0.19	0.28	0.37	0.10	0.16	0.21
Goats	0.12	0.18	0.23	0.11	0.17	0.22
Camels	1.6	2.4	3.2	1.3	1.9	2.6
Horses	1.4	2.1	2.8	1.1	1.6	2.2
Mules and Asses	0.76	1.14	1.51	0.60	0.90	1.2
Poultry[b]	0.078	0.117	0.157	0.012	0.018	0.023

The range of estimates reflects cool to warm climates. Climate regions are defined in terms of annual average temperature as follows: Cool = less than 15°C; Temperate = 15°C to 25°C inclusive; and Warm = greater than 25°C. The Cool, Temperate and Warm regions are estimated using MCFs of 1 %, 1.5 % and 2 %, respectively.

a Temp. = Temperate climate region.

b Chickens, ducks, and turkeys.

All estimates are ±20 %.

Sources: Emission factors developed from: feed intake values and feed digestibilities used to develop the enteric fermentation emission factors (see Appendix A); MCF, and B_o values reported in Woodbury and Hashimoto (1993). All manure is assumed to be managed in dry systems, which is consistent with the manure management system usage reported in Woodbury and Hashimoto (1993).

The ranges of values shown in Table 4-5 reflect the range of Methane Conversion Factor values of 1 to 2 per cent. The higher value is appropriate for manure managed in warm climates, while the lower value is appropriate for manure managed in cooler and dryer climates. A middle value is assigned to temperate conditions. The uncertainty in the emission factors remains substantial, however, because field measurements are required to validate the laboratory measurements that form the basis for the MCFs used in the analysis. Appendix B, at the end of this section, summarises the data used to estimate the emission factors shown in Table 4-6.

The climate data collected in Step 1 is used to select the emission factors from Table 4-6. A weighted average emission factor for each animal type is computed by multiplying the percentages of the animal populations in each climate region by the emission factor for each climate region. For example, if sheep in a developing country were 25 per cent in a temperate region and 75 per cent in a warm region, the emission factor for sheep would be estimated at about 0.2 kg/head/yr as follows:

$$\text{Emission Factor} = (25\% \times 0.16) + (75\% \times 0.21) = 0.1975 \text{ kg/head/yr.}$$

An alternative way of handling these calculations is to sub-divide the category of sheep into two populations: one in warm and one in temperate region. Calculations could then be done separately and summed.

Because the manure from cattle, buffalo, and swine is managed in a variety of ways, including both dry and liquid systems, the variations in manure management practices among regions and countries must be considered to develop emission factors for these animals. Table 4-6 presents emission factors based on regional manure management practices described in Safley et al. (1992).

TABLE 4-6
MANURE MANAGEMENT EMISSION FACTORS FOR CATTLE, SWINE AND BUFFALO

Regional Characteristics	Livestock Type	Emission Factor by Climate Region[a] (kg/head/yr)		
		Cool	Temperate	Warm
North America: Liquid-based systems are commonly used for dairy and swine manure. Non-dairy manure is usually managed as a solid and deposited on pastures or ranges.	Dairy Cattle	36	54	76
	Non-dairy Cattle	1	2	3
	Swine	10	14	18
Western Europe: Liquid/slurry and pit storage systems are commonly used for cattle and swine manure. Limited cropland is available for spreading manure.	Dairy Cattle	14	44	81
	Non-dairy Cattle	6	20	38
	Swine	3	10	19
	Buffalo	3	8	17
Eastern Europe: Solid based systems are used for the majority of manure. About one-third of livestock manure is managed in liquid-based systems.	Dairy Cattle	6	19	33
	Non-dairy Cattle	4	13	23
	Swine	4	7	11
	Buffalo	3	9	16
Oceania: Virtually all livestock manure is managed as a solid on pastures and ranges. About half of the swine manure is managed in anaerobic lagoons.	Dairy Cattle	31	32	33
	Non-dairy Cattle	5	6	7
	Swine	20	20	20
Latin America: Almost all livestock manure is managed as a solid on pastures and ranges. Buffalo manure is deposited on pastures and ranges.	Dairy Cattle	0	1	2
	Non-dairy Cattle	1	2	1
	Swine	0	1	2
	Buffalo	1	1	2
Africa: Almost all livestock manure is managed as a solid on pastures and ranges.	Dairy Cattle	1	1	1
	Non-dairy Cattle	0	1	1
	Swine	0	1	2
Middle East: Over two-thirds of cattle manure is deposited on pastures and ranges. About one-third of swine manure is managed in liquid-based systems. Buffalo manure is burned for fuel or managed as a solid.	Dairy Cattle	1	2	2
	Non-Dairy Cattle	1	1	1
	Swine	1	3	6
	Buffalo	4	5	5
Asia: About half of cattle manure is used for fuel with the remainder managed in dry systems. Almost 40% of swine manure is managed as a liquid. Buffalo manure is managed in drylots and deposited in pastures and ranges.	Dairy Cattle	7	16	27
	Non-dairy Cattle	1	1	2
	Swine	1	4	7
	Buffalo	1	2	3
Indian Subcontinent: About half of cattle and buffalo manure is used for fuel with the remainder managed in dry systems. About one-third of swine manure is managed as a liquid.	Dairy Cattle	5	5	6
	Non-dairy Cattle	2	2	2
	Swine	3	4	6
	Buffalo	4	5	5

[a] Cool climates have an average temperature below 15°C; temperate climates have an average temperature from 15°C to 25°C inclusive; warm climates have an average temperature above 25°C. All climate categories are not necessarily represented within every region. For example, there are no significant warm areas in Eastern or Western Europe. Similarly, there are no significant cool areas in Africa and the Middle East. See Appendix B for the derivation of these emission factors.

Note: Significant buffalo populations do not exist in North America, Oceania, or Africa.

As shown in the table, the emission factors for dairy cattle range between 81 kg/head/yr in warm parts of Western Europe to 0 kg/head/yr in cool parts of Latin America. The emission factors for non-dairy cattle range between 38 kg/head/yr in warm parts of Western Europe to 1 kg/head/yr in cool parts of North America and Latin America. In addition to climate, the range of emission factors is due to the manure management practices used in each region. For example, the emission factors for North American dairy cattle manure and European dairy and non-dairy cattle manure are relatively high because the manure is often managed using liquid systems that promote methane production. The emission factors for North American non-dairy cattle and for all animals in Africa and the Middle East are relatively low because their manure is generally managed using dry systems that do not promote methane production.

To select emission factors from Table 4-6, first identify the appropriate region, such as Latin America. Within that region, identify the animal type of interest. For that animal type three values are given for the three climate regions. Compute a weighted average emission factor for the animal type by multiplying the percentages of the animal population in each climate region by the emission factor for each climate region. Appendix B summarises the estimates of manure management system usage and MCFs that underlie the emission factors in Table 4-6.

As with the other manure management emission factors, there is substantial uncertainty in the estimates shown in Table 4-6 because field measurements are required to validate the laboratory measurements that form the basis for the MCFs used in the analysis, and because there is uncertainty and variability in the manner in which manure is managed in each region.

TIER 1: STEP 3 – TOTAL EMISSION

To estimate total emission the selected emission factors are multiplied by the associated animal population and summed. The emission estimates should be reported in gigagrams (Gg). Because the emission factors are reported in kilograms per head per year, the total emissions in Gg is estimated as follows for each animal category:

$$\text{emission factor (kg/head/yr)} \times \text{population (head)} / (10^6 \text{ kg/Gg}) = \text{emissions Gg/yr.}$$

As a point of reference, in 1990 total annual global methane emissions from domestic livestock enteric fermentation were of the order of 0.060 to 0.100 Gg (Gibbs and Johnson, 1993). Enteric fermentation emissions from countries with large populations of livestock may be on the order of 0.001 to 0.005 Gg per year. Countries with smaller populations of livestock would likely have emissions of less than 0.001 Gg per year.

In 1990 total annual global methane emissions from manure management was on the order of 0.010 to 0.018 Gg (Woodbury and Hashimoto, 1993). Manure management emissions from countries where manure is managed in liquid-based systems may be on the order of 0.001 to 0.002 Gg per year. Countries where manure is not managed in liquid-based systems would likely have emissions of much less than 0.001 Gg per year.

4.2.4 Tier 2 Approach for Methane Emissions From Enteric Fermentation

The Tier 2 approach is recommended for estimating methane emissions from enteric fermentation from cattle for those countries with large cattle populations. As contrasted with the Tier 1 method, this approach requires much more detailed information on the cattle population. Using this detailed information, more precise estimates of the cattle emission factors are developed. When the Tier 2 method is used the default emission factors listed in Tier 1 for cattle are not used.

This Tier 2 approach is similar to the August 1991 OECD method (OECD, 1991), with some modifications:

- The Blaxter and Clapperton (1965) equation is replaced with a recommended set of methane conversion rate "rules of thumb."
- Feed energy intake requirements for pregnancy have been added.
- The energy requirements required for grazing have been reduced based on newly available data from AAC (1990).
- The equations used to relate gross energy intake to net energy used by the animal have been made more general to fit a wider variety of feed conditions.

The three steps outlined for Tier 1 are also used here.

ENTERIC FERMENTATION
TIER 2: STEP 1 – LIVESTOCK POPULATION

To develop precise estimates of emissions, cattle should be divided into categories of relatively homogeneous groups. For each category a representative animal is chosen and characterised for the purpose of estimating an emission factor. Table 4-7 presents a set of recommended representative cattle types. Three main categories, Mature Dairy Cattle, Mature Non-dairy Cattle, and Young Cattle, are recommended as the minimum set of representative types. The subcategories listed should be used when data are available. In particular, the sub-population of cows providing milk to calves should be identified among non-dairy cattle because the feed intake necessary to support milk production can be substantial. In some countries the feedlot category is needed so that the implications of the high-grain diets can be incorporated.

TABLE 4-7
RECOMMENDED REPRESENTATIVE CATTLE TYPES

Main Categories	Subcategories
Mature Dairy Cattle	Dairy Cows used principally for commercial milk production
Mature Non-dairy Cattle	Mature Females: •Beef Cows: used principally for producing beef steers and heifers •Multiple-Use Cows: used for milk production, draft power, and other uses Mature Males: •Breeding Bulls: used principally for breeding purposes •Draft Bullocks: used principally for draft power
Young Cattle	Pre-Weaned Calves Growing Heifers, Steers/Bullocks and Bulls Feedlot-Fed Steers and Heifers on High-Grain Diets

For each of the representative animal types defined, the following information is required:

- annual average population (number of head);
- average daily feed intake (megajoules (MJ) per day and kg per day of dry matter); and
- methane conversion rate (percentage of feed energy converted to methane).

Generally, data on average daily feed intake are not available, particularly for grazing animals. Consequently, the following data should be collected for estimating the feed intake for each representative animal type[4]:

- weight (kg);
- average weight gain per day (kg);[5]
- feeding situation: confined animals; animals grazing good quality pasture; and animals grazing over very large areas;
- milk production per day (kg/day);[6]
- average amount of work performed per day (hours/day);
- percentage of cows that give birth in a year;[7] and
- feed digestibility (%).[8]

These data should be obtained from country-specific cattle evaluations. Some data, such as weight, weight gain, and milk production, may be available from production statistics. Care should be taken to use the live cattle weights, as contrasted with slaughter weights. Appendix A, at the end of this section, lists the data used to develop the default emission factors presented in Tier 1. Individual country data can be compared to the data presented in Appendix A to ensure that the data collected are reasonable.

Data on methane conversion rates are also not generally available. The following rules of thumb are recommended for the methane conversion rates:

- <u>Developed Countries</u>. A 6 per cent conversion rate (±0.5 per cent) is recommended for all cattle in developed countries except feedlot cattle consuming diets with a large quantity of grain. For feedlot cattle on high grain diets a rate of 4 per cent (±0.5 per cent) is recommended. In circumstances where good feed is available (i.e., high digestibility and high energy value) the lower bounds of these ranges can be used. When poorer feed is available, the higher bounds are more appropriate.
- <u>Developing Countries</u>. Several recommendations are made for different animal management situations in developing countries:

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[4] In many, if not most, cattle management circumstances, the principal driving factors that affect feed intake are: weight, milk production and feed digestibility.

[5] This may be assumed to be zero for mature animals.

[6] Milk production is required for dairy cows and non-dairy cows providing milk to calves.

[7] This is only relevant for mature cows.

[8] Feed digestibility is defined as the proportion of energy in the feed that is not excreted in the faeces. Digestibility is commonly expressed as a percentage (%). Common ranges for feed digestibility for cattle are 50% to 60% for crop by-products and rangelands; 60% to 70% for good pastures, good preserved forages, and grain-supplemented forage-based diets; and 75% to 85% for grain-based diets fed in feedlots.

– All dairy cows and young cattle are recommended to have a conversion rate of 6.0 per cent (±0.5 per cent). These cattle are generally the best-fed cattle in these regions.
– All non-dairy cattle, other than young stall-fed animals, consuming low-quality crop by-products, are recommended to have a conversion rate of 7.0 per cent (±0.5 per cent) because feed resources are particularly poor in many cases in these regions.
– Grazing cattle are recommended to have a conversion rate of 6.0 per cent (±0.5 per cent), except for grazing cattle in Africa, which are recommended to have a rate of 7.0 per cent (±0.5 per cent) because of the forage characteristics found in many portions of tropical Africa.

These rules of thumb are a rough guide based on the general feed characteristics and production practices found in many developed and developing countries. Country-specific exceptions to these general rules of thumb should be taken into consideration as necessary based on detailed data from cattle experts.

ENTERIC FERMENTATION
TIER 2: STEP 2 – EMISSION FACTORS

The emission factors for each category of cattle are estimated based on the feed intake and methane conversion rate for the category. Feed intake is estimated based on the feed energy requirements of the representative animals, subject to feed-intake limitations. The net energy system described in NRC (1984 and 1989) is recommended as the starting point for the estimates. Because the NRC system was developed for feeding conditions in temperate regions, several adjustments were made to avoid potential biases when applied to evaluate feed-energy intakes for tropical cattle (see Appendix C). Comparisons with alternative feeding systems (e.g., ARC, 1980) indicate that the emissions estimates are not sensitive to the feeding system used as the basis for making the estimates.

The net energy system specifies the amount of feed energy required for the physiological functions of cattle, including maintenance, growth and lactation. Feed energy requirements for work have also been estimated, and are included in this analysis for the draft animals in developing countries. Energy requirements for pregnancy have also been added for the portion of cows that give birth in each year. The following information is required to estimate feed energy intakes:

- *Maintenance*
  Maintenance refers to the apparent feed energy required to keep the animal in energy equilibrium, i.e., there is no gain or loss of energy in the body tissues (Jurgens, 1988). For cattle, net energy for maintenance (NE_m) has been estimated to be a function of the weight of the animal raised to the 0.75 power (NRC, 1984):

EQUATION 1

$$NE_m \text{ (MJ/day)} = 0.322 \times (\text{weight in kg})^{0.75}$$

NRC (1989) recommends that lactating dairy cows be allowed a slightly higher maintenance allowance:

$$NE_m \text{ (MJ/day)} = 0.335 \times (\text{weight in kg})^{0.75} \quad \text{dairy cows\}}$$

- *Feeding*
  Additional energy is required for animals to obtain their food. Grazing animals require more energy for this activity than do stall-fed animals. The following energy requirements are added for this activity based on their feeding situation:[9]

EQUATION 2
NE_{feed} =
Confined animals (pens and stalls): no additional NE_m;
Animals grazing good quality pasture: 17 % of NE_m; and
Animals grazing over very large areas: 37 % of NE_m.

- *Growth*
  The energy requirements for growth can be estimated as a function of the weight of the animal and the rate of weight gain. NRC (1989) presents formulae for large- and small-frame males and females, the estimates of which vary by about ± 25 per cent. The equation for large-frame females is recommended, which is about the average for the four types:

EQUATION 3
NE_g (MJ/day) = 4.18 x {(0.035 $W^{0.75}$ x $WG^{1.119}$) + WG}

  where:
  W = animal weight in kilograms (kg); and
  WG = weight gain in kg per day.

  The relationships for NE_g were developed for temperate agriculture conditions, and may over-estimate energy requirements for tropical conditions, particularly for draft animals that may have a lower fat content in their weight gain (Graham, 1985). However, no data are available for improving the estimates at this time.

- *Lactation*
  Net energy for lactation has been expressed as a function of the amount of milk produced and its fat content (NRC, 1989):

EQUATION 4
NE_l (MJ/day) = kg of milk/day x (1.47 + 0.40 x Fat %)

  At 4.0 per cent fat, the NE_l in MJ/day is about 3.1 x kg of milk per day.

- *Draft Power*
  Various authors have summarised the energy intake requirements for providing draft power (e.g., Lawrence, 1985; Bamualim and Kartiarso, 1985; and Ibrahim, 1985). The strenuousness of the work performed by the animal influences the energy requirements, and consequently a wide range of energy requirements have been estimated. The values by Bamualim and Kartiarso show that about 10 per cent of

[9] The original OECD method recommended slightly higher energy additions. These revised figures are based on newly-published information in AAC (1990).

NE_m requirements are required per hour of typical work for draft animals. This value is used as follows:

EQUATION 5

$$NE_{draft}\ (MJ/day) = 0.10 \times NE_m \times \text{hours of work per day}$$

- *Pregnancy*
  Daily energy requirements for pregnancy are presented in NRC (1984). Integrating these requirements over a 281-day gestation period yields the following equation:

EQUATION 6

$$NE_{pregnancy}\ (MJ/281\text{-day period}) = 28 \times \text{calf birth weight in kg}$$

The following equation can be used to estimate the approximate calf birth weight as a function of the cow's weight:[10]

EQUATION 7

$$\text{Calf birth weight (kg)} = 0.266 \times (\text{cow weight in kg})^{0.79}$$

Manipulating Equations 6 and 7, in conjunction with Equation 1, shows that the NE required for pregnancy is about 7.5 per cent of NE_m for the range of cow sizes considered in this analysis. Therefore, a factor of 7.5 per cent of NE_m is added to account for the energy required for pregnancy for the portion of cows giving birth each year.

Based on these equations, each of the net energy components for each of the cattle categories can be estimated from the data collected in Step 1: weight in kilograms; feeding situation; weight gain per day in kilograms; milk production in kilograms of 4 per cent fat-corrected milk; number of hours of work performed per day; and portion that give birth.

These net energy requirements must be translated into gross energy intakes. Also, by estimating the gross energy intake, the net energy estimates can be checked for reasonableness against expected ranges of feed intake as a percentage of animal weight. To estimate gross energy intake, the relationship between the net energy values and gross energy values of different feeds must be considered. This relationship can be summarised briefly as follows:

Digestible Energy	=	Gross Energy - Faecal Losses
Metabolisable Energy	=	Digestible Energy - Urinary and Combustible Gas Losses
Net Energy	=	Metabolisable Energy - Heat Increment

Net Energy	=	Gross Energy - Faecal Losses - Urinary and Combustible Gas Losses - Heat Increment

[10] This species-specific equation from Robbins and Robbins (1979) was adjusted to the mean cow and calf weight of a typical beef breed of cattle. This adjustment increases the coefficient in the equation from 0.214 to 0.266.

The quantitative relationship among these energy values varies among feed types. Additionally, the values depend on how the feeds are prepared and fed, and the level at which they are fed. For the purposes of this method, simplifying assumptions are used to derive a relationship between net energy and digestible energy that is reasonably representative for the range of diets typically fed to cattle. Gross energy intake is then estimated using this relationship and the digestibility data collected in Step 1.

Given the digestibility of the feed (defined in Step 1), a general relationship between digestible energy and metabolisable energy can be used as follows (NRC, 1984):

EQUATION 8

Metabolisable Energy (ME) = 0.82 x Digestible Energy (DE)

Equation 8 is a simplified relationship; larger (smaller) methane conversion rates would tend to reduce (increase) the coefficient to values below (above) 0.82.

NRC (1984) presents separate quantitative relationships between metabolisable energy and net energy used for growth versus net energy used for other functions. Using Equation 8, the NRC relationships can be re-arranged to quantify the ratio of NE to DE, as follows:

EQUATION 9

$$NE/DE = 1.123 - (4.092 \times 10^{-3} \times DE\%) + (1.126 \times 10^{-5} \times (DE\%)^2) - 25.4/DE\%$$

EQUATION 10

$$NE_g/DE = 1.164 - (5.160 \times 10^{-3} \times DE\%) + (1.308 \times 10^{-5} \times (DE\%)^2) - 37.4/DE\%$$

where:

NE/DE = the ratio of net energy consumed for maintenance, lactation, work and pregnancy to digestible energy consumed;

NE_g/DE = the ratio of net energy consumed for growth to digestible energy consumed; and

DE% = digestible energy as percentage of gross energy, expressed in per cent (e.g., 65%).

Because the NRC (1984) relationships were developed based on diets with relatively high digestibilities (generally above 65 per cent), they may not be appropriate for the relatively low digestibility diets that are commonly found in tropical livestock systems. In particular, the non-linear nature of the relationships could appear to increase the estimates of feed intake for low-digestibility feeds. An apparent increase in feed intake would lead to an apparent increase in emissions estimates.