CHAPTER 10

EMISSIONS FROM LIVESTOCK AND MANURE MANAGEMENT

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10.1 INTRODUCTION

This chapter provides guidance on methods to estimate emissions of methane from Enteric Fermentation in livestock, and methane and nitrous oxide emissions from Manure Management. CO_2 emissions from livestock are not estimated because annual net CO_2 emissions are assumed to be zero – the CO_2 photosynthesized by plants is returned to the atmosphere as respired CO_2. A portion of the C is returned as CH_4 and for this reason CH_4 requires separate consideration.

Livestock production can result in methane (CH_4) emissions from enteric fermentation and both CH_4 and nitrous oxide (N_2O) emissions from livestock manure management systems. Cattle are an important source of CH_4 in many countries because of their large population and high CH_4 emission rate due to their ruminant digestive system. Methane emissions from manure management tend to be smaller than enteric emissions, with the most substantial emissions associated with confined animal management operations where manure is handled in liquid-based systems. Nitrous oxide emissions from manure management vary significantly between the types of management system used and can also result in indirect emissions due to other forms of nitrogen loss from the system. The calculation of the nitrogen loss from manure management systems is also an important step in determining the amount of nitrogen that will ultimately be available in manure applied to managed soils, or used for feed, fuel, or construction purposes – emissions that are calculated in Chapter 11, Section 11.2 (N_2O emissions from managed soils).

The methods for estimating CH_4 and N_2O emissions from livestock require definitions of livestock subcategories, annual populations and, for higher Tier methods, feed intake and characterisation. The procedures employed to define livestock subcategories, develop population data, and characterize feed are described in Section 10.2 (Livestock Population and Feed Characterisation). Suggested feed digestibility coefficients for various livestock categories have been provided to help estimation of feed intake for use in calculation of emissions from enteric and manure sources. A coordinated livestock characterisation as described in Section 10.2 should be used to ensure consistency across the following source categories:

- Section 10.3 - CH_4 emissions from Enteric Fermentation;
- Section 10.4 - CH_4 emissions from Manure Management;
- Section 10.5 - N_2O emissions from Manure Management (direct and indirect);
- Chapter 11, Section 11.2 - N_2O emissions from Managed Soils (direct and indirect).

10.2 LIVESTOCK POPULATION AND FEED CHARACTERISATION

10.2.1 Steps to define categories and subcategories of livestock

Good practice is to identify the appropriate method for estimating emissions for each source category, and then base the characterisation on the most detailed requirements identified for each livestock species. The livestock characterisation used by a country will probably undergo iterations as the needs of each source category are assessed during the emissions estimation process (see Figure 10.1, Decision Tree for Livestock Population Characterisation). The steps are:

- **Identify livestock species applicable to each emission source category:** The livestock species that contribute to more than one emission source category should first be listed. These species are typically: cattle, buffalo, sheep, goats, swine, horses, camels, mules/asses, and poultry.
- **Review the emission estimation method for each relevant source category**: For the source categories of Enteric Fermentation and Manure Management, identify the emission estimating method for each species for that source category. For example, enteric fermentation emissions from cattle, buffalo, and sheep should each be examined to assess whether the trend or level of emissions warrant a Tier 2 or Tier 3 emissions estimate. Similarly, manure management methane emissions from cattle, buffalo, swine, and poultry should

be examined to determine whether the Tier 2 or Tier 3 emissions estimate is appropriate. Existing inventory estimates can be used to conduct this assessment. If no inventory has been developed to date, Tier 1 emission estimates should be calculated to provide initial estimates for conducting this assessment. See Volume 1, Chapter 4 (Methodological Choice and Identification of Key Categories) for guidance on the general issues of methodological choice.

- **Identify the most detailed characterisation required for each livestock species**: Based on the assessments for each species under each source category, identify the most detailed characterisation required to support each emissions estimate for each species. Typically, the 'Basic' characterisation can be used across all relevant source categories if the enteric fermentation and manure sources are both estimated with their Tier 1 methods. An 'Enhanced' characterisation should be used to estimate emissions across all the relevant sources if the Tier 2 method is used for either enteric fermentation or manure.

10.2.2 Choice of method

TIER 1: BASIC CHARACTERISATION FOR LIVESTOCK POPULATIONS

Basic characterisation for Tier 1 is likely to be sufficient for most animal species in most countries. For this approach it is *good practice* to collect the following livestock characterisation data to support the emissions estimates:

Livestock species and categories: A complete list of all livestock populations that have default emission factor values must be developed (e.g., dairy cows, other cattle, buffalo, sheep, goats, camels, llamas, alpacas, deer, horses, rabbits, mules and asses, swine, and poultry) if these categories are relevant to the country. More detailed categories should be used if the data are available. For example, more accurate emission estimates can be made if poultry populations are further subdivided (e.g., layers, broilers, turkeys, ducks, and other poultry), as the waste characteristics among these different populations varies significantly.

Annual population: If possible, inventory compilers should use population data from official national statistics or industry sources. Food and Agriculture Organisation (FAO) data can be used if national data are unavailable. Seasonal births or slaughters may cause the population size to expand or contract at different times of the year, which will require the population numbers to be adjusted accordingly. It is important to fully document the method used to estimate the annual population, including any adjustments to the original form of the population data as it was received from national statistical agencies or from other sources.

Annual average populations are estimated in various ways, depending on the available data and the nature of the animal population. In the case of static animal populations (e.g., dairy cows, breeding swine, layers), estimating the annual average population may be as simple as obtaining data related to one-time animal inventory data. However, estimating annual average populations for a growing population (e.g., meat animals, such as broilers, turkeys, beef cattle, and market swine) requires more evaluation. Most animals in these growing populations are alive for only part of a complete year. Animals should be included in the populations regardless if they were slaughtered for human consumption or die of natural causes. Equation 10.1 estimates the annual average of livestock population.

EQUATION 10.1
ANNUAL AVERAGE POPULATION

$$AAP = Days\_alive \bullet \left(\frac{NAPA}{365} \right)$$

Where:

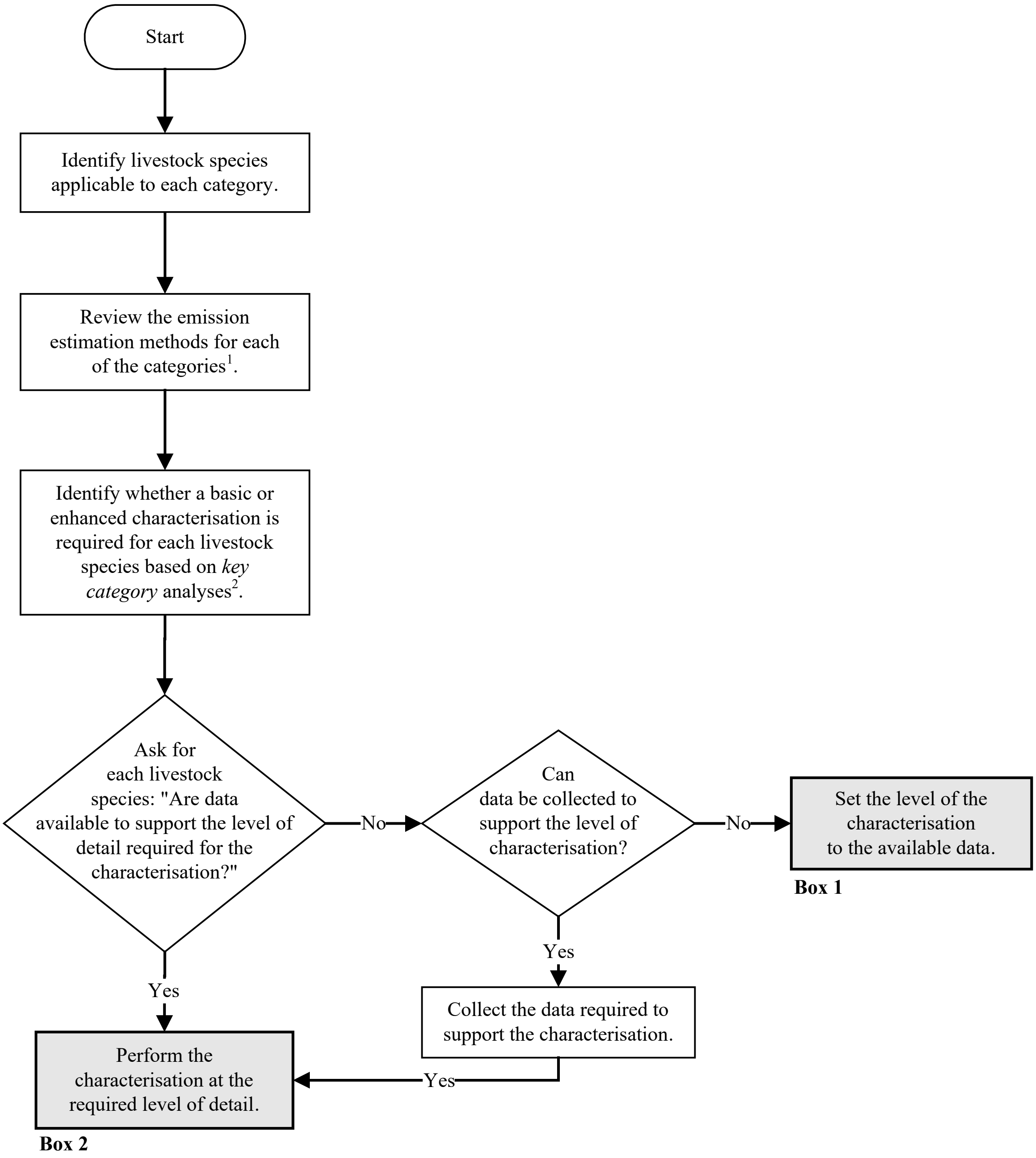
AAP = annual average population

NAPA = number of animals produced annually

Broiler chickens are typically grown approximately 60 days before slaughter. Estimating the average annual population as the number of birds grown and slaughtered over the course of a year would greatly overestimate the population, as it would assume each bird lived the equivalent of 365 days. Instead, one should estimate the average annual population as the number of animals grown divided by the number of growing cycles per year. For example, if broiler chickens are typically grown in flocks for 60 days, an operation could turn over approximately 6 flocks of chickens over the period of one year. Therefore, if the operation grew 60,000 chickens in a year, their average annual population would be 9,863 chickens. For this example the equation would be:

Annual average population = 60 days ● 60,000 / 365 days / yr = 9,863 chickens

Figure 10.1 Decision tree for livestock population characterisation



Note:
1: These categories include: CH_4 Emission from Enteric Fermentation, CH_4 Emission from Manure Management, and N_2O Emission from Manure Management.
2: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

Dairy cows and milk production: The dairy cow population is estimated separately from other cattle (see Table 10.1). Dairy cows 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 cow population is comprised of two well-defined segments: (i) high-producing (also called improved) breeds in commercial operations; and (ii) low-producing cows managed with traditional methods. These two segments can be combined, or can be evaluated separately by defining two dairy cow categories. However, the dairy cow category does not include cows kept principally to produce calves for meat or to provide draft power. Low productivity multi-purpose cows should be considered as other cattle.

Dairy buffalo may be categorized in a similar manner to dairy cows.

Data on the average milk production of dairy cows are also required. Milk production data are used in estimating an emission factor for enteric fermentation using the Tier 2 method. Country-specific data sources are preferred, but FAO data may also be used. These data are expressed in terms of kilograms of whole fresh milk produced per year per dairy cow. If two or more dairy cow categories are defined, the average milk production per cow is required for each category.

TIER 2: ENHANCED CHARACTERISATION FOR LIVESTOCK POPULATIONS

The Tier 2 livestock characterisation requires detailed information on:

- Definitions for livestock subcategories;
- Livestock population by subcategory, with consideration for estimation of annual population as per Tier 1; and
- Feed intake estimates for the typical animal in each subcategory.

The livestock population subcategories are defined to create relatively homogenous sub-groupings of animals. By dividing the population into these subcategories, country-specific variations in age structure and animal performance within the overall livestock population can be reflected.

The Tier 2 characterisation methodology seeks to define animals, animal productivity, diet quality and management circumstances to support a more accurate estimate of feed intake for use in estimating methane production from enteric fermentation. The same feed intake estimates should be used to provide harmonised estimates of manure and nitrogen excretion rates to improve the accuracy and consistency of CH_4 and N_2O emissions from manure management.

Definitions for livestock subcategories

It is *good practice* to classify livestock populations into subcategories for each species according to age, type of production, and sex. Representative livestock categories for doing this are shown in Table 10.1. Further subcategories are also possible:

- Cattle and buffalo populations should be classified into at least three main subcategories: mature dairy, other mature, and growing cattle. Depending on the level of detail in the emissions estimation method, subcategories can be further classified based on animal or feed characteristics. For example, growing / fattening cattle could be further subdivided into those cattle that are fed a high-grain diet and housed in dry lot vs. those cattle that are grown and finished solely on pasture.
- Subdivisions similar to those used for cattle and buffalo can be used to further segregate the sheep population in order to create subcategories with relatively homogenous characteristics. For example, growing lambs could be further segregated into lambs finished on pasture vs. lambs finished in a feedlot. The same approach applies to national goat herds.
- Subcategories of swine could be further segregated based on production conditions. For example, growing swine could be further subdivided into growing swine housed in intensive production facilities vs. swine that are grown under free-range conditions.
- Subcategories of poultry could be further segregated based on production conditions. For example, poultry could be divided on the basis of production under confined or free-range conditions.

For large countries or for countries with distinct regional differences, it may be useful to designate regions and then define categories within those regions. Regional subdivisions may be used to represent differences in climate, feeding systems, diet, and manure management. However, this further segregation is only useful if correspondingly detailed data are available on feeding and manure management system usage by these livestock categories.

TABLE 10.1
REPRESENTATIVE LIVESTOCK CATEGORIES[1,2]

Main categories	**Subcategories**
Mature Dairy Cow or Mature Dairy Buffalo	• High-producing cows that have calved at least once and are used principally for milk production • Low-producing cows that have calved at least once and are used principally for milk production
Other Mature Cattle or Mature Non-dairy Buffalo	Females: • Cows used to produce offspring for meat • Cows used for more than one production purpose: milk, meat, draft Males: • Bulls used principally for breeding purposes • Bullocks used principally for draft power
Growing Cattle or Growing Buffalo	• Calves pre-weaning • Replacement dairy heifers • Growing / fattening cattle or buffalo post-weaning • Feedlot-fed cattle on diets containing > 90 % concentrates
Mature Ewes	• Breeding ewes for production of offspring and wool production • Milking ewes where commercial milk production is the primary purpose
Other Mature Sheep (>1 year)	• No further sub-categorisation recommended
Growing Lambs	• Intact males • Castrates • Females
Mature Swine	• Sows in gestation • Sows which have farrowed and are nursing young • Boars that are used for breeding purposes
Growing Swine	• Nursery • Finishing • Gilts that will be used for breeding purposes • Growing boars that will be used for breeding purposes
Chickens	• Broiler chickens grown for producing meat • Layer chickens for producing eggs, where manure is managed in dry systems (e.g., high-rise houses) • Layer chickens for producing eggs, where manure is managed in wet systems (e.g., lagoons) • Chickens under free-range conditions for egg or meat production
Turkeys	• Breeding turkeys in confinement systems • Turkeys grown for producing meat in confinement systems • Turkeys under free-range conditions for meat production
Ducks	• Breeding ducks • Ducks grown for producing meat
Others (for example)	• Camels • Mules and Asses • Llamas, Alpacas • Fur bearing animals • Rabbits • Horses • Deer • Ostrich • Geese

[1] Source IPCC Expert Group

[2] Emissions should only be considered for livestock species used to produce food, fodder or raw materials used for industrial processes.

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

- annual average population (number of livestock or poultry as per calculations for Tier 1);
- average daily feed intake (megajoules (MJ) per day and / or kg per day of dry matter); and
- methane conversion factor (percentage of feed energy converted to methane).

Generally, data on average daily feed intake are not available, particularly for grazing livestock. Consequently, the following general data should be collected for estimating the feed intake for each representative animal category:

- weight (kg);
- average weight gain per day (kg)[1];
- feeding situation: confined, grazing, pasture conditions;
- milk production per day (kg/day) and fat content (%)[2];
- average amount of work performed per day (hours day^{-1});
- percentage of females that give birth in a year[3];
- wool growth;
- number of offspring; and
- feed digestibility (%).

Feed intake estimates

Tier 2 emissions estimates require feed intakes for a representative animal in each subcategory. Feed intake is typically measured in terms of gross energy (e.g., megajoules (MJ) per day) or dry matter (e.g., kilograms (kg) per day). Dry matter is the amount of feed consumed (kg) after it has been corrected for the water content in the complete diet. For example, consumption of 10 kg of a diet that contains 70% dry matter would result in a dry matter intake of 7 kg. To support the enteric fermentation Tier 2 method for cattle, buffalo, and sheep (see Section 10.3), detailed data requirements and equations to estimate feed intake are included in guidance below. Constants in the equations have been combined to simplify overall equation formats. The remainder of this subsection presents the typical data requirements and equations used to estimate feed intake for cattle, buffalo, and sheep. Feed intake for other species can be estimated using similar country-specific methods appropriate for each.

For all estimates of feed intake, *good practice* is to:

- Collect data to describe the animal's typical diet and performance in each subcategory;
- Estimate feed intake from the animal performance and diet data for each subcategory.

In some cases, the equations may be applied on a seasonal basis, for example under conditions in which livestock gain weight in one season and lose weight in another. This approach may require a more refined variation of Tier 2 or more complex Tier 3 type methodology.

The following animal performance data are required for each animal subcategory to estimate feed intake for the subcategory:

- **Weight (W), kg:** Live-weight data should be collected for each animal subcategory. It is unrealistic to perform a complete census of live-weights, so live-weight data should be obtained from representative sample studies or statistical databases if these already exist. Comparing live-weight data with slaughter-weight data is a useful cross-check to assess whether the live-weight data are representative of country conditions. However, slaughter-weight data should not be used in place of live-weight data as it fails to account for the complete weight of the animal. Additionally, it should be noted that the relationship between live-weight and slaughter-weight varies with breed and body condition. For cattle, buffalo and

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

[2] Milk production data are required for dairy animals. These can be estimated for non-dairy animals providing milk to young, where data are available.

[3] This is only relevant for mature females.

mature sheep, the yearly average weight for each animal category (e.g., mature beef cows) is needed. For young sheep, weights are needed at birth, weaning, one year of age or at slaughter if slaughter occurs within the year.

- **Average weight gain per day (WG), kg day^{-1}**: Data on average weight gain are generally collected for feedlot animals and young growing animals. Mature animals are generally assumed to have no net weight gain or loss over an entire year. Mature animals frequently lose weight during the dry season or during temperature extremes and gain weight during the following season. However, increased emissions associated with this weight change are likely to be small. Reduced intakes and emissions associated with weight loss are largely balanced by increased intakes and emissions during the periods of gain in body weight.
- **Mature weight (MW), kg**: The mature weight of the adult animal of the inventoried group is required to define a growth pattern, including the feed and energy required for growth. For example, mature weight of a breed or category of cattle or buffalo is generally considered to be the body weight at which skeletal development is complete. The mature weight will vary among breeds and should reflect the animal's weight when in moderate body condition. This is termed 'reference weight' (ACC, 1990) or 'final shrunk body weight' (NRC, 1996). Estimates of mature weight are typically available from livestock specialists and producers.
- **Average number of hours worked per day:** For draft animals, the average number of hours worked per day must be determined.
- **Feeding situation:** The feeding situation that most accurately represents the animal subcategory must be determined using the definitions shown below (Table 10.5). If the feeding situation lies between the definitions, the feeding situation should be described in detail. This detailed information may be needed when calculating the enteric fermentation emissions, because interpolation between the feeding situations may be necessary to assign the most appropriate coefficient. Table 10.5 defines the feeding situations for cattle, buffalo, and sheep. For poultry and swine, the feeding situation is assumed to be under confinement conditions and consequently the activity coefficient (C_a)is assumed to be zero as under these conditions very little energy is expended in acquiring feed. Activity coefficients have not been developed for free-ranging swine or poultry, but in most instances these livestock subcategories are likely to represent a small proportion of the national inventory.
- **Mean winter temperature (ºC)**: Detailed feed intake models consider ambient temperature, wind speed, hair and tissue insulation and the heat of fermentation (NRC, 2001; AAC, 1990) and are likely more appropriate in Tier 3 applications. A more general relationship adapted from North America data suggest adjusting the Cf_i of Equation 10.3 for maintenance requirements of open-lot fed cattle in colder climates according to the following equation (Johnson, 1986):

EQUATION 10.2
COEFFICIENT FOR CALCULATING NET ENERGY FOR MAINTENANCE

$$Cf_i(in\_cold) = Cf_i + 0.0048 \bullet (20 - °C)$$

Where:

Cf_i = a coefficient which varies for each animal category as shown in Table 10.4 (Coefficients for calculating NE_m), MJ day^{-1} kg^{-1}

°C = mean daily temperature during winter season

Considering the average temperature during winter months, net energy for maintenance (NE_m) requirements may increase by as much as 30% in northern North America. This increase in feed use for maintenance is also likely associated with greater methane emissions.

- **Average daily milk production (kg day^{-1}):** These data are for milking ewes, dairy cows and buffalo. The average daily production should be calculated by dividing the total annual production by 365, or reported as average daily production along with days of lactation per year, or estimated using seasonal production divided by number of days per season. If using seasonal production data, the emission factor must be developed for that seasonal period.
- **Fat content (%):** Average fat content of milk is required for lactating cows, buffalo, and sheep producing milk for human consumption.
- **Percent of females that give birth in a year:** This is collected only for mature cattle, buffalo, and sheep.

- **Number of off spring produced per year:** This is relevant to female livestock that have multiple births per year (e.g., ewes).
- **Feed digestibility (DE%):** The portion of gross energy (GE) in the feed not excreted in the faeces is known as digestible feed. The feed digestibility is commonly expressed as a percentage (%) of GE or TDN (total digestible nutrients). That percentage of feed that is not digested represents the % of dry matter intake that will be excreted as faeces. Typical digestibility values for a range of livestock classes and diet types are presented in Table 10.2 as a guideline. For ruminants, common ranges of feed digestibility are 45-55% for crop by-products and range lands; 55-75% for good pastures, good preserved forages, and grain supplemented forage-based diets; and 75-85% for grain-based diets fed in feedlots. Variations in diet digestibility results in major variations in the estimate of feed needed to meet animal requirements and consequently associated methane emissions and amounts of manure excreted. It is also important to note that digestibility, intake, and growth are co-dependent phenomena. For example, a low digestibility will lead to lower feed intake and consequently reduced growth. Conversely, feeds with high digestibility will often result in a higher feed intake and increased growth. A 10% error in estimating DE will be magnified to 12 to 20% when estimating methane emissions and even more (20 to 45%) for manure excretion (volatile solids).

  Digestibility data should be based on measured values for the dominant feeds or forages being consumed by livestock with consideration for seasonal variation. In general, the digestibility of forages decreases with increasing maturity and is typically lowest during the dry season. Due to significant variation, digestibility coefficients should be obtained from local scientific data wherever possible. Although a complete census of digestibility is considered unrealistic, at a minimum digestibility data from research studies should be consulted. While developing the digestibility data, associated feed characteristic data should also be recorded when available, such as measured values for Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), crude protein, and the presence of anti-nutritional factors (e.g., alkaloids, phenolics, % ash). NDF and ADF are feed characteristics measured in the laboratory that are used to indicate the nutritive value of the feed for ruminant livestock. Determination of these values can enable DE to be predicted as defined in the recent dairy NRC (2001). The concentration of crude protein in the feed can be used in the process of estimating nitrogen excretion (Section 10.5.2).
- **Average annual wool production per sheep (kg yr^{-1}):** The amount of wool produced in kilograms (after drying out but before scouring) is needed to estimate the amount of energy allocated for wool production.

TABLE 10.2
REPRESENTATIVE FEED DIGESTIBILITY FOR VARIOUS LIVESTOCK CATEGORIES

Main categories	Class	Digestibility (DE%)
Swine	• Mature Swine – confinement • Growing Swine - confinement • Swine – free range	• 70 - 80% • 80 - 90% • 50 - 70% [1]
Cattle and other ruminants	• Feedlot animals fed with > 90% concentrate diet; • Pasture fed animals; • Animals fed – low quality forage	• 75 - 85% • 55 - 75% • 45 - 55%
Poultry	• Broiler Chickens –confinement • Layer Hens – confinement • Poultry – free range • Turkeys – confinement • Geese – confinement	• 85 - 93% • 70 - 80% • 55 - 90% [1] • 85 - 93% • 80 - 90%

[1] The range in digestibility of feed consumed by free-range swine and poultry is extremely variable due to the selective nature of these diets. Often it is likely that the amount of manure produced in these classes will be limited by the amount of feed available for consumption as opposed to its degree of digestibility. In instances where feed is not limiting and high quality feed sources are readily accessible for consumption, digestibility may approach values that are similar to those measured under confinement conditions.

Gross energy calculations

Animal performance and diet data are used to estimate feed intake, which is the amount of energy (MJ/day) an animal needs for maintenance and for activities such as growth, lactation, and pregnancy. For inventory compilers who have well-documented and recognised country-specific methods for estimating intake based on animal performance data, it is *good practice* to use the country-specific methods. The following section provides methods for estimating gross energy intake for the key ruminant categories of cattle, buffalo and sheep. The equations listed in Table 10.3 are used to derive this estimate. If no country-specific methods are available, intake should be calculated using the equations listed in Table 10.3. As shown in the table, separate equations are used to estimate net energy requirements for sheep as compared with cattle and buffalo. The equations used to calculate GE are as follows:

TABLE 10.3
SUMMARY OF THE EQUATIONS USED TO ESTIMATE DAILY GROSS ENERGY INTAKE FOR CATTLE, BUFFALO AND SHEEP

Metabolic functions and other estimates	Equations for cattle and buffalo	Equations for sheep
Maintenance (NE_m)	Equation 10.3	Equation 10.3
Activity (NE_a)	Equation 10.4	Equation 10.5
Growth (NE_g)	Equation 10.6	Equation 10.7
Lactation (NE_l)*	Equation 10.8	Equations 10.9 and 10.10
Draft Power (NE_{work})	Equation 10.11	NA
Wool Production (NE_{wool})	NA	Equation 10.12
Pregnancy (NE_p)*	Equation 10.13	Equation 10.13
Ratio of net energy available in diet for maintenance to digestible energy consumed (REM)	Equation 10.14	Equation 10.14
Ratio of net energy available for growth in a diet to digestible energy consumed (REG)	Equation 10.15	Equation 10.15
Gross Energy	Equation 10.16	Equation 10.16

Source: Cattle and buffalo equations based on NRC (1996) and sheep based on AFRC (1993).
NA means 'not applicable'.
* Applies only to the proportion of females that give birth.

***Net energy for maintenance*:** (NE_m) is the net energy required for maintenance, which is the amount of energy needed to keep the animal in equilibrium where body energy is neither gained nor lost (Jurgen, 1988).

EQUATION 10.3
NET ENERGY FOR MAINTENANCE

$$NE_m = Cf_i \bullet (Weight)^{0.75}$$

Where:

NE_m = net energy required by the animal for maintenance, MJ day^{-1}

Cf_i = a coefficient which varies for each animal category as shown in Table 10.4 (Coefficients for calculating NE_m), MJ day^{-1} kg^{-1}

Weight = live-weight of animal, kg

Net energy for activity: (NE_a) is the net energy for activity, or the energy needed for animals to obtain their food, water and shelter. It is based on its feeding situation rather than characteristics of the feed itself. As presented in Table 10.3, the equation for estimating NE_a for cattle and buffalo is different from the equation used for sheep. Both equations are empirical with different definitions for the coefficient C_a.

EQUATION 10.4
NET ENERGY FOR ACTIVITY (FOR CATTLE AND BUFFALO)

$$NE_a = C_a \bullet NE_m$$

Where:

NE_a = net energy for animal activity, MJ day^{-1}

C_a = coefficient corresponding to animal's feeding situation (Table 10.5, Activity coefficients)

NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day^{-1}

EQUATION 10.5
NET ENERGY FOR ACTIVITY (FOR SHEEP)

$$NE_a = C_a \bullet (weight)$$

Where:

NE_a = net energy for animal activity, MJ day^{-1}

C_a = coefficient corresponding to animal's feeding situation (Table 10.5), MJ day^{-1} kg^{-1}

weight = live-weight of animal, kg

For Equations 10.4 and 10.5, the coefficient C_a corresponds to a representative animal's feeding situation as described earlier. Values for C_a are shown in Table 10.5. If a mixture of these feeding situations occurs during the year, NE_a must be weighted accordingly.

TABLE 10.4
COEFFICIENTS FOR CALCULATING NET ENERGY FOR MAINTENANCE (NE_M)

Animal category	**Cf_i (MJ d^{-1} kg^{-1})**	**Comments**
Cattle/Buffalo (non-lactating cows, steers and juveniles)	0.322	Non-lactating dairy, beef and multi-purpose cows, steers and juveniles
Cattle/Buffalo (lactating cows)	0.386	Maintenance energy requirements are 20% higher during lactation
Cattle/Buffalo (bulls)	0.370	Maintenance energy requirements are 15% higher for intact males
Sheep (lamb to 1 year)	0.236	This value can be increased by 15% for intact males
Sheep (older than 1 year)	0.217	This value can be increased by 15% for intact males.

Source: NRC (1996) and AFRC (1993).

TABLE 10.5
ACTIVITY COEFFICIENTS CORRESPONDING TO ANIMAL'S FEEDING SITUATION

Situation	Definition	C_a
Cattle and Buffalo (unit for C_a is dimensionless)		
Stall	Animals are confined to a small area (i.e., tethered, pen, barn) with the result that they expend very little or no energy to acquire feed.	0.00
Pasture	Animals are confined in areas with sufficient forage requiring modest energy expense to acquire feed.	0.17
Grazing large areas	Animals graze in open range land or hilly terrain and expend significant energy to acquire feed.	0.36
Sheep (unit for C_a = MJ d^{-1} kg^{-1})		
Housed ewes	Animals are confined due to pregnancy in final trimester (50 days).	0.0090
Grazing flat pasture	Animals walk up to 1000 meters per day and expend very little energy to acquire feed.	0.0107
Grazing hilly pasture	Animals walk up to 5,000 meters per day and expend significant energy to acquire feed.	0.0240
Housed fattening lambs	Animals are housed for fattening.	0.0067
Source: NRC (1996) and AFRC (1993).		

***Net energy for growth*:** (NE_g) is the net energy needed for growth (i.e., weight gain). Equation 10.6 is based on NRC (1996). Equation 10.7 is based on Gibbs *et al.* (2002). Constants for conversion from calories to joules and live to shrunk and empty body weight have been incorporated into the equation.

EQUATION 10.6
NET ENERGY FOR GROWTH (FOR CATTLE AND BUFFALO)

$$NE_g = 22.02 \bullet \left(\frac{BW}{C \bullet MW} \right)^{0.75} \bullet WG^{1.097}$$

Where:

NE_g = net energy needed for growth, MJ day^{-1}

BW = the average live body weight (BW) of the animals in the population, kg

C = a coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls (NRC, 1996)

MW = the mature live body weight of an adult animal in moderate body condition, kg

WG = the average daily weight gain of the animals in the population, kg day^{-1}

EQUATION 10.7
NET ENERGY FOR GROWTH (FOR SHEEP)

$$NE_g = \frac{WG_{lamb} \bullet \left(a + 0.5b\left(BW_i + BW_f\right)\right)}{365}$$

Where:

NE_g = net energy needed for growth, MJ day^{-1}

WG_{lamb} = the weight gain ($BW_f - BW_i$), kg yr^{-1}

BW_i = the live bodyweight at weaning, kg

BW_f = the live bodyweight at 1-year old or at slaughter (live-weight) if slaughtered prior to 1 year of age, kg

a, b = constants as described in Table 10.6.

Note that lambs will be weaned over a period of weeks as they supplement a milk diet with pasture feed or supplied feed. The time of weaning should be taken as the time at which they are dependent on milk for half their energy supply.

The NE_g equation used for sheep includes two empirical constants (a and b) that vary by animal species/category (Table 10.6).

TABLE 10.6
CONSTANTS FOR USE IN CALCULATING NE_G FOR SHEEP

Animal species/category	a (MJ kg^{-1})	b (MJ kg^{-2})
Intact males	2.5	0.35
Castrates	4.4	0.32
Females	2.1	0.45

Source: AFRC (1993).

***Net energy for lactation*: (**NE_l) is the net energy for lactation. For cattle and buffalo the net energy for lactation is expressed as a function of the amount of milk produced and its fat content expressed as a percentage (e.g., 4%) (NRC, 1989):

EQUATION 10.8
NET ENERGY FOR LACTATION (FOR BEEF CATTLE, DAIRY CATTLE AND BUFFALO)

$$NE_l = Milk \bullet (1.47 + 0.40 \bullet Fat)$$

Where:

NE_l = net energy for lactation, MJ day^{-1}

Milk = amount of milk produced, kg of milk day^{-1}

Fat = fat content of milk, % by weight.

Two methods for estimating the net energy required for lactation (NE_l) are presented for sheep. The first method (Equation 10.9) is used when the amount of milk produced is known, and the second method (Equation 10.8) is used when the amount of milk produced is not known. Generally, milk production is known for ewes kept for commercial milk production, but it is not known for ewes that suckle their young to weaning. With a known amount of milk production, the total annual milk production is divided by 365 days to estimate the average daily milk production in kg/day (Equation 10.9). When milk production is not known, AFRC (1990) indicates that for a single birth, the milk yield is about 5 times the weight gain of the lamb. For multiple births, the total annual milk production can be estimated as five times the combined weight gain of all lambs birthed by a single ewe. The daily average milk production is estimated by dividing the resulting estimate by 365 days as shown in Equation 10.10.

EQUATION 10.9
NET ENERGY FOR LACTATION FOR SHEEP (MILK PRODUCTION KNOWN)

$$NE_l = Milk \bullet EV_{milk}$$

Where:

NE_l = net energy for lactation, MJ day^{-1}

Milk = amount of milk produced, kg of milk day^{-1}

EV_{milk} = the net energy required to produce 1 kg of milk. A default value of 4.6 MJ/kg (AFRC, 1993) can be used which corresponds to a milk fat content of 7% by weight

EQUATION 10.10
NET ENERGY FOR LACTATION FOR SHEEP (MILK PRODUCTION UNKNOWN)

$$NE_l = \left[\frac{(5 \bullet WG_{wean})}{365}\right] \bullet EV_{milk}$$

Where:

NE_l = net energy for lactation, MJ day^{-1}

WG_{wean} = the weight gain of the lamb between birth and weaning, kg

EV_{milk} = the energy required to produce 1 kg of milk, MJ kg^{-1}. A default value of 4.6 MJ kg^{-1} (AFRC, 1993) can be used.

Net energy for work: (NE_{work}) is the net energy for work. It is used to estimate the energy required for draft power for cattle and buffalo. 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 percent of a day's NE_m requirements are required per hour for typical work for draft animals. This value is used as follows:

EQUATION 10.11
NET ENERGY FOR WORK (FOR CATTLE AND BUFFALO)

$$NE_{work} = 0.10 \bullet NE_m \bullet Hours$$

Where:

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

NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day^{-1}

Hours = number of hours of work per day

Net energy for wool production: (NE_{wool}) is the average daily net energy required for sheep to produce a year of wool. The NE_{wool} is calculated as follows:

EQUATION 10.12
NET ENERGY TO PRODUCE WOOL (FOR SHEEP)

$$NE_{wool} = \left(\frac{EV_{wool} \bullet Production_{wool}}{365}\right)$$

Where:

NE_{wool} = net energy required to produce wool, MJ day^{-1}

EV_{wool} = the energy value of each kg of wool produced (weighed after drying but before scouring), MJ kg^{-1}. A default value of 24 MJ kg^{-1} (AFRC, 1993) can be used for this estimate.

$Production_{wool}$ = annual wool production per sheep, kg yr^{-1}

Net energy for pregnancy: (NE_p) is the energy required for pregnancy. For cattle and buffalo, the total energy requirement for pregnancy for a 281-day gestation period averaged over an entire year is calculated as 10% of NE_m. For sheep, the NE_p requirement is similarly estimated for the 147-day gestation period, although the percentage varies with the number of lambs born (Table 10.7, Constant for Use in Calculating NE_p in Equation 10.13). Equation 10.13 shows how these estimates are applied.

EQUATION 10.13
NET ENERGY FOR PREGNANCY (FOR CATTLE/BUFFALO AND SHEEP)

$$NE_p = C_{pregnancy} \bullet NE_m$$

Where:

NE_p = net energy required for pregnancy, MJ day^{-1}

$C_{pregnancy}$ = pregnancy coefficient (see Table 10.7)

NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day^{-1}

TABLE 10.7
CONSTANTS FOR USE IN CALCULATING NE_P IN EQUATION 10.13

Animal category	$C_{pregnancy}$
Cattle and Buffalo	0.10
Sheep	
Single birth	0.077
Double birth (twins)	0.126
Triple birth or more (triplets)	0.150

Source: Estimate for cattle and buffalo developed from data in NRC (1996). Estimates for sheep developed from data in AFRC (1993), taking into account the inefficiency of energy conversion.

When using NE_p to calculate GE for cattle and sheep, the NE_p estimate must be weighted by the portion of the mature females that actually go through gestation in a year. For example, if 80% of the mature females in the animal category give birth in a year, then 80% of the NE_p value would be used in the GE equation below.

To determine the proper coefficient for sheep, the portion of ewes that have single births, double births, and triple births is needed to estimate an average value for $C_{pregnancy}$. If these data are not available, the coefficient can be calculated as follows:

- If the number of lambs born in a year divided by the number of ewes that are pregnant in a year is less than or equal to 1.0, then the coefficient for single births can be used.
- If the number of lambs born in a year divided by the number of ewes that are pregnant in a year exceeds 1.0 and is less than 2.0, calculate the coefficient as follows:

$$C_{pregnancy} = [(0.126 \bullet \text{Double birth fraction}) + (0.077 \bullet \text{Single birth fraction})]$$

Where:

Double birth fraction = [(lambs born / pregnant ewes) – 1]

Single birth fraction = [1 – Double birth fraction]

Ratio of net energy available in diet for maintenance to digestible energy consumed (REM): For cattle, buffalo and sheep, the ratio of net energy available in a diet for maintenance to digestible energy consumed (REM) is estimated using the following equation (Gibbs and Johnson, 1993):

EQUATION 10.14
RATIO OF NET ENERGY AVAILABLE IN A DIET FOR MAINTENANCE TO DIGESTIBLE ENERGY CONSUMED

$$REM = \left[1.123 - \left(4.092 \bullet 10^{-3} \bullet DE\%\right) + \left[1.126 \bullet 10^{-5} \bullet (DE\%)^2\right] - \left(\frac{25.4}{DE\%}\right)\right]$$

Where:

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

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

***Ratio of net energy available for growth in a diet to digestible energy consumed (REG)*:** For cattle, buffalo and sheep the ratio of net energy available for growth (including wool growth) in a diet to digestible energy consumed (REG) is estimated using the following equation (Gibbs and Johnson, 1993):

EQUATION 10.15
RATIO OF NET ENERGY AVAILABLE FOR GROWTH IN A DIET TO DIGESTIBLE ENERGY CONSUMED

$$REG = \left[1.164 - \left(5.160 \bullet 10^{-3} \bullet DE\% \right) + \left[1.308 \bullet 10^{-5} \bullet \left(DE\% \right)^2 \right] - \left(\frac{37.4}{DE\%} \right) \right]$$

Where:

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

***Gross energy, GE*:** As shown in Equation 10.16, GE requirement is derived based on the summed net energy requirements and the energy availability characteristics of the feed(s). Equation 10.16 represents *good practice* for calculating GE requirements for cattle and sheep using the results of the equations presented above.

In using Equation 10.16, only those terms relevant to each animal category are used (see Table 10.3).

EQUATION 10.16
GROSS ENERGY FOR CATTLE/BUFFALO AND SHEEP

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

Where:

GE = gross energy, MJ day^{-1}

NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day^{-1}

NE_a = net energy for animal activity (Equations 10.4 and 10.5), MJ day^{-1}

NE_l = net energy for lactation (Equations 10.8, 10.9, and 10.10), MJ day^{-1}

NE_{work} = net energy for work (Equation 10.11), MJ day^{-1}

NE_p = net energy required for pregnancy (Equation 10.13), MJ day^{-1}

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation 10.14)

NE_g = net energy needed for growth (Equations 10.6 and 10.7), MJ day^{-1}

NE_{wool} = net energy required to produce a year of wool (Equation 10.12), MJ day^{-1}

REG = ratio of net energy available for growth in a diet to digestible energy consumed (Equation 10.15)

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

Once the values for GE are calculated for each animal subcategory, the feed intake in units of kilograms of dry matter per day (kg day^{-1}) should also be calculated. To convert from GE in energy units to dry matter intake (DMI), divide GE by the energy density of the feed. A default value of 18.45 MJ kg^{-1} of dry matter can be used if feed-specific information is not available. The resulting daily dry matter intake should be in the order of 2% to 3% of the body weight of the mature or growing animals. In high producing milk cows, intakes may exceed 4% of body weight.

Feed intake estimates using a simplified Tier 2 method

***Prediction of DMI for cattle based on body weight and estimated dietary net energy concentration (NE_{ma}) or digestible energy values (DE%)*:** It is also possible to predict dry matter intake for mature and growing cattle based on body weight of the animal and either the NE_{ma} concentration of the feed (NRC, 1996) or DE%. Dietary NE_{ma} concentration can range from 3.0 to 9.0 MJ kg^{-1} of dry matter. Typical values for high, moderate and low quality diets are presented in Table 10.8. These figures can also be used to estimate NE_{ma} values for mixed diets based on estimate of diet quality. For example, a mixed forage-grain diet could be assumed to have a NE_{ma} value similar to that of a high-quality forage diet. A mixed grain-straw diet could be assumed to have a NE_{ma} value similar to that of a moderate quality forage. Nutritionists within specific geographical areas should be able to provide advice with regard to the selection of NE_{ma} values that are more representative of locally fed diets.

Dry matter intake for growing and finishing cattle is estimated using the following equation:

EQUATION 10.17
ESTIMATION OF DRY MATTER INTAKE FOR GROWING AND FINISHING CATTLE

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.2444 \bullet NE_{ma} - 0.0111 \bullet NE_{ma}{}^{2} - 0.472\right)}{NE_{ma}} \right]$$

Where:

DMI = dry matter intake, kg day^{-1}

BW = live body weight, kg

NE_{ma} = estimated dietary net energy concentration of diet or default values in Table 10.8, MJ kg^{-1}

Dry matter intake for mature beef cattle is estimated using the following equation:

EQUATION 10.18a
ESTIMATION OF DRY MATTER INTAKE FOR MATURE BEEF CATTLE

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.0119 \bullet NE_{ma}{}^{2} + 0.1938\right)}{NE_{ma}} \right]$$

Where:

DMI = dry matter intake, kg day^{-1}

BW = live body weight, kg

NE_{ma} = estimated dietary net energy concentration of diet or default values given in Table 10.8, MJ kg^{-1}

For mature dairy cows consuming low quality, often tropical forages, the following alternative equation for estimating dry matter intake based on DE% can be used (NRC, 1989):

EQUATION 10.18b
ESTIMATION OF DRY MATTER INTAKE FOR MATURE DAIRY COWS

$$DMI = \left[\frac{\left(\frac{(5.4 \bullet BW)}{500}\right)}{\left(\frac{(100 - DE\%)}{100}\right)} \right]$$

Where:

DMI = dry matter intake, kg day^{-1}

BW = live body weight, kg

DE%= digestible energy expressed as a percentage of gross energy (typically 45-55% for low quality forages)

Equations 10.17, 10.18a, and 10.18b provide a good check to the main Tier 2 method to predict feed intake. They can be viewed as asking 'what is an expected intake for a given diet quality?' and used to independently predict DMI from BW and diet quality (NE_{ma} or DE%). In contrast, the main Tier 2 method predicts DMI based on how much feed must be consumed to meet estimated requirements (i.e., NE_m and NE_g) and does not consider the biological capacity of the animal to in fact consume the predicted quantity of feed. Consequently, the simplified Tier 2 method can be used to confirm that DMI values derived from the main Tier 2 method are biologically realistic. These estimates are also subject to the cross check that dry matter intake should be in the order of 2% to 3% of the bodyweight of the mature or growing animals.

TABLE 10.8
EXAMPLES OF NE_{MA} CONTENT OF TYPICAL DIETS FED TO CATTLE FOR ESTIMATION OF DRY MATTER INTAKE IN EQUATIONS 10.17 AND 10.18

Diet type	NE_{ma} (MJ (kg dry matter)$^{-1}$)
High grain diet > 90%	7.5 - 8.5
High quality forage (e.g., vegetative legumes & grasses)	6.5 - 7.5
Moderate quality forage (e.g., mid season legume & grasses)	5.5 - 6.5
Low quality forage (e.g., straws, mature grasses)	3.5 - 5.5

Source: Estimates obtained from predictive models in NRC (1996), NE_{ma} can also be estimated using the equation: NE_{ma} = REM x 18.45 x DE% / 100.

10.2.3 Uncertainty assessment

The first step in collecting data should be to investigate existing national statistics, industry sources, research studies and FAO statistics. The uncertainty associated with populations will vary widely depending on source, but should be known within $\pm$20%. Often, national livestock population statistics already have associated uncertainty estimates in which case these should be used. If published data are not available from these sources, interviews of key industry and academic experts can be undertaken. Estimates of digestibility are also particularly important in Tier 2 estimates of gross energy intake. Uncertainty estimates for digestibility estimates may be as high as $\pm$20%. Volume 1, Chapter 3 (Uncertainties) describes how to elicit expert judgement for uncertainty ranges. Similar expert elicitation protocols can be used to obtain the information required for the livestock characterisation if published data and statistics are not available.

10.2.4 Characterisation for livestock without species: Specific emission estimation methods

Some countries may have domesticated livestock for which there are currently no Tier 1 or Tier 2 emissions estimating methods (e.g., llamas, alpacas, wapiti, emus, and ostriches). *Good practice* in estimating emissions from these livestock is to first assess whether their emissions are likely to be significant enough to warrant characterising them and developing country-specific emission factors. Volume 1, Chapter 4 (Methodological Choice and Identification of Key Categories) presents guidance for assessing the significance of individual source categories within the national inventory. Similar approaches can be used to assess the importance of sub-source categories (i.e. species) within a source category. If the emissions from a particular sub-species are determined to be significant, then country-specific emission factors should be developed, and a characterisation should be performed to support the development of the emission factors. Research into the estimation of emission levels from these non-characterized species should be encouraged. The data and methods used to characterise the animals should be well documented.

As emissions estimation methods are not available for these animals, approximate emission factors based on 'order of magnitude calculations' are appropriate for conducting the assessment of the significance of their emissions. One approach for developing the approximate emission factors is to use the Tier 1 emissions factor for an animal with a similar digestive system and to scale the emissions factor using the ratio of the weights of the animals raised to the 0.75 power. The Tier 1 emission factors can be classified by digestive system as follows:

- Ruminant animals: Cattle, Buffalo, Sheep, Goats, Camels
- Non-ruminant herbivores: Horses, Mules/Asses
- Poultry: Chickens, Ducks, Turkeys, Geese
- Non-poultry monogastric animals: Swine

For example, an approximate enteric fermentation methane emissions factor for alpacas could be estimated from the emissions factor for sheep (also a ruminant animal) as follows:

$$\text{Approximate emissions factor} = [(\text{alpaca weight}) / (\text{sheep weight})]^{0.75} \bullet \text{sheep emissions factor}$$

Similarly, an approximate manure methane emissions factor for ostriches could be estimated using the Tier 1 emission factor for chickens. Approximate emission factors developed using this method can only be used to assess the significance of the emissions from the animals, and are not considered sufficiently accurate for estimating emissions as part of a national inventory.

10.3 METHANE EMISSIONS FROM ENTERIC FERMENTATION

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. The amount of methane that is released depends on the type of digestive tract, age, and weight of the animal, and the quality and quantity of the feed consumed. Ruminant livestock (e.g., cattle, sheep) are major sources of methane with moderate amounts produced from non-ruminant livestock (e.g., pigs, horses). The ruminant gut structure fosters extensive enteric fermentation of their diet.

Digestive system

The type of digestive system has a significant influence on the rate of methane emission. Ruminant livestock have an expansive chamber, the rumen, at the fore-part of their digestive tract that supports intensive microbial fermentation of their diet which yields several nutritional advantages including the capacity to digest cellulose in their diet. The main ruminant livestock are cattle, buffalo, goats, sheep, deer and camelids. Non-ruminant livestock (horses, mules, asses) and monogastric livestock (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. Although, the extent of methane production may also be affected by the composition of the diet. Feed intake is positively related to animal size, growth rate, and production (e.g., milk production, wool growth, or pregnancy).

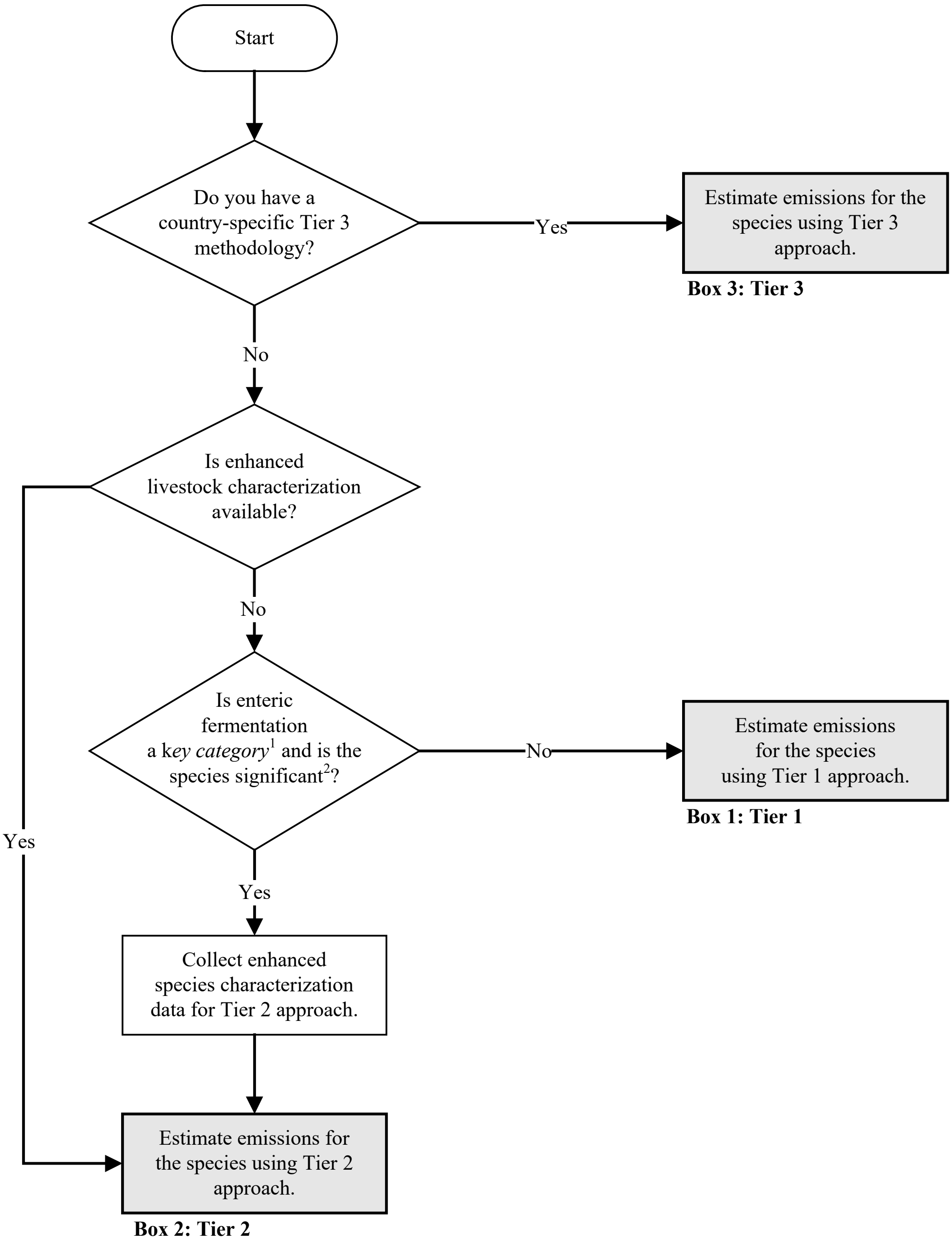
To reflect the variation in emission rates among animal species, the population of animals should be divided into subgroups, and an emission rate per animal is estimated for each subgroup. Types of population subgroups are provided in Section 10.2 (Livestock and Feed Characterisation). The amount of methane emitted by a population subgroup is calculated by multiplying the emission rate per animal by the number of animals within the subgroup.

Natural wild ruminants are not considered in the derivation of a country’s emission estimate. Emissions should only be considered from animals under domestic management (e.g., farmed deer, elk, and buffalo).

10.3.1 Choice of method

It is *good practice* to choose the method for estimating methane emissions from enteric fermentation according to the decision tree in Figure 10.2. The method for estimating methane emission from enteric fermentation requires three basic steps:

Figure 10.2 Decision Tree for CH_4 Emissions from Enteric Fermentation



Note:

1: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

2: As a rule of thumb, a livestock species would be significant if it accounts for 25-30% or more of emissions from the source category.

Step 1: Divide the livestock population into subgroups and characterize each subgroup as described in Section 10.2. It is recommended that national experts use annual averages estimated with consideration for the impact of production cycles and seasonal influences on population numbers.

Step 2: Estimate emission factors for each subgroup in terms of kilograms of methane per animal per year.

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 three approaches:

Tier 1

A simplified approach that relies on default emission factors either drawn from the literature or calculated using the more detailed Tier 2 methodology. The Tier 1 method is likely to be suitable for most animal species in countries where enteric fermentation is not a key source category, or where enhanced characterization data are not available. When approximate enteric emissions are derived by extrapolation from main livestock categories they should be considered to be a Tier 1 method.

Tier 2

A more complex approach that requires detailed country-specific data on gross energy intake and methane conversion factors for specific livestock categories. The Tier 2 method should be used if enteric fermentation is a key source category for the animal category that represents a large portion of the country's total emissions.

Tier 3

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. This approach could employ the development of sophisticated models that consider diet composition in detail, concentration of products arising from ruminant fermentation, seasonal variation in animal population or feed quality and availability, and possible mitigation strategies. Many of these estimates would be derived from direct experimental measurements. Although countries are encouraged to go beyond the Tier 2 method presented below when data are available, these more complex analyses are only briefly discussed here. A Tier 3 method should be subjected to a wide degree of international peer review such as that which occurs in peer-reviewed publications to ensure that they improve the accuracy and / or precision of estimates.

Countries with large populations of domesticated animal species for which there are no IPCC default emission factors (e.g., llamas and alpacas) are encouraged to develop national methods that are similar to the Tier 2 method and are based on well-documented research (if it is determined that emissions from these livestock are significant). The approach is described in Section 10.2.4 under the heading 'Characterisation for livestock without species-specific emission estimation methods' for more information.

Table 10.9 summarises the suggested approaches for the livestock emissions included in this inventory.

10.3.2 Choice of emission factors

Tier 1 Approach for methane emissions from Enteric Fermentation

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.

Step 1: Animal population

The animal population data should be obtained using the approach described in Section 10.2.

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 have been drawn from previous studies, and are organised by region for ease of use.

The data used to estimate the default emission factors for enteric fermentation are presented in Annex 10A.1 at the end of this section.

TABLE 10.9
SUGGESTED EMISSIONS INVENTORY METHODS FOR ENTERIC FERMENTATION

Livestock	Suggested emissions inventory methods
Dairy Cow	Tier 2[a]/Tier 3
Other Cattle	Tier 2[a]/Tier 3
Buffalo	Tier 1/Tier 2
Sheep	Tier 1/Tier 2
Goats	Tier 1
Camels	Tier 1
Horses	Tier 1
Mules and Asses	Tier 1
Swine	Tier 1
Poultry	Not developed
Other (e.g., Llamas, Alpacas, Deer)	Tier 1

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

Table 10.10 shows the enteric fermentation emission factors for each of the animal species 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 Annex 10A.1). Table 10.11 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 10.11 are broadly representative of the emission rates within each of the regions described, emission factors vary within each region. 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.

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

To select emission factors from Tables 10.10 and 10.11, identify the region most applicable to the country being evaluated. Scrutinise the tabulations in Annex 10A.1 to ensure that the underlying animal characteristics such as weight, growth rate and milk production used to develop the emission factors are similar to the conditions in the country. 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.

Note that using the same Tier 1 emission factors for the inventories of successive years means that no allowance is being made for changing livestock productivity, such as increasing milk productivity or trend in live weight. If it is important to capture the trend in methane emission that results from a trend in livestock productivity, then livestock emissions can become a key source category based on trend and a Tier 2 calculation should be used.

TABLE 10.10
ENTERIC FERMENTATION EMISSION FACTORS FOR TIER 1 METHOD[1]
(KG CH_4 HEAD^{-1} YR^{-1})

Livestock	Developed countries	Developing countries	Liveweight
Buffalo	55	55	300 kg
Sheep	8	5	65 kg - developed countries; 45 kg - developing countries
Goats	5	5	40 kg
Camels	46	46	570 kg
Horses	18	18	550 kg
Mules and Asses	10	10	245 kg
Deer	20	20	120 kg
Alpacas	8	8	65 kg
Swine	1.5	1.0	
Poultry	Insufficient data for calculation	Insufficient data for calculation	
Other (e.g., Llamas)	To be determined[1]	To be determined[1]	

All estimates have an uncertainty of ±30-50%.

Sources: Emission factors for buffalo and camels from Gibbs and Johnson (1993). Emission factors for other livestock from Crutzen *et al*., (1986), Alpacas from Pinares-Patino *et al*., 2003; Deer from Clark *et al*., 2003 .

[1] One approach for developing the approximate emission factors is to use the Tier 1 emissions factor for an animal with a similar digestive system and to scale the emissions factor using the ratio of the weights of the animals raised to the 0.75 power. Liveweight values have been included for this purpose. Emission factors should be derived on the basis of characteristics of the livestock and feed of interest and should not be restricted solely to within regional characteristics.

Step 3: Total emission

To estimate total emission, the selected emission factors are multiplied by the associated animal population (Equation 10.19) and summed (Equation 10.20):

EQUATION 10.19
ENTERIC FERMENTATION EMISSIONS FROM A LIVESTOCK CATEGORY

$$Emissions = EF_{(T)} \bullet \left(\frac{N_{(T)}}{10^6} \right)$$

Where:

Emissions = methane emissions from Enteric Fermentation, Gg CH_4 yr^{-1}

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4 head^{-1} yr^{-1}

$N_{(T)}$ = the number of head of livestock species / category T in the country

T = species/category of livestock

EQUATION 10.20
TOTAL EMISSIONS FROM LIVESTOCK ENTERIC FERMENTATION

$$\text{Total } CH_{4\text{Enteric}} = \sum_i E_i$$

Where:

Total $CH_{4\text{Enteric}}$ = total methane emissions from Enteric Fermentation, Gg CH_4 yr^{-1}

E_i = is the emissions for the i^{th} livestock categories and subcategories

TABLE 10.11
TIER 1 ENTERIC FERMENTATION EMISSION FACTORS FOR CATTLE[1]

Regional characteristics	Cattle category	Emission factor [2,3] (kg CH_4 $head^{-1}$ yr^{-1})	Comments
North America: Highly productive commercialized 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	128	Average milk production of 8,400 kg $head^{-1}$ yr^{-1}.
	Other Cattle	53	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	117	Average milk production of 6,000 kg $head^{-1}$ yr^{-1}.
	Other Cattle	57	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	99	Average milk production of 2,550 kg $head^{-1}$ yr^{-1}.
	Other Cattle	58	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	100	Average milk production of 2,200 kg $head^{-1}$ yr^{-1}.
	Other Cattle	60	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	72	Average milk production of 800 kg $head^{-1}$ yr^{-1}
	Other Cattle	56	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	68	Average milk production of 1,650 kg $head^{-1}$ yr^{-1}
	Other Cattle	47	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 are smaller than those found in most other regions.	Dairy	46	Average milk production of 475 kg $head^{-1}$ yr^{-1}
	Other Cattle	31	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	58	Average milk production of 900 kg $head^{-1}$ yr^{-1}
	Other Cattle	27	Includes cows, bulls, and young. Young comprise a large portion of the population

[1] Emission factors should be derived on the basis of the characteristics of the cattle and feed of interest and need not be restricted solely to within regional characteristics.

[2] IPCC Expert Group, values represent averages within region, where applicable the use of more specific regional milk production data is encouraged. Existing values were derived using Tier 2 method and the data in Tables 10 A.1 and 10A. 2.

[3] The following assumptions have been made in deriving these values: i) mature weights of animals have been used; ii) cows have been assumed to be non-lactating as lactation levels were low and, iii) the mix of bulls and castrates among "males" was undetermined as Cfi value for castrates was not specified.

Tier 2 Approach for methane emissions from Enteric Fermentation

The Tier 2 method is applied to more disaggregated livestock population categories and used to calculate emission factors, as opposed to default values. The key considerations for the Tier 2 method are the development of emission factors and the collection of detailed activity data.

Step 1: Livestock population

The animal population data and related activity data should be obtained following the approach described in Section 10.2.

Step 2: Emission factors

When the Tier 2 method is used, emission factors are estimated for each animal category using the detailed data developed in Step 1.

The emission factors for each category of livestock are estimated based on the gross energy intake and methane conversion factor for the category. The gross energy intake data should be obtained using the approach described in Section 10.2. The following two sub-steps need to be completed to calculate the emission factor under the Tier 2 method:

1. Obtaining the methane conversion factor (Y_m)

The extent to which feed energy is converted to CH_4 depends on several interacting feed and animal factors. If CH_4 conversion factors are unavailable from country-specific research, the values provided in Table 10.12, Cattle/Buffalo CH_4 conversion factors, can be used for cattle and buffalo. These general estimates are a rough guide based on the general feed characteristics and production practices found in many developed and developing countries. When good feed is available (i.e., high digestibility and high energy value) the lower bounds should be used. When poorer feed is available, the higher bounds are more appropriate. A CH_4 conversion factor of zero is assumed for all juveniles consuming only milk (i.e., milk-fed lambs as well as calves).

Due to the importance of Y_m in driving emissions, substantial ongoing research is aimed at improving estimates of Y_m for different livestock and feed combinations. Such improvement is most needed for animals fed on tropical pastures as the available data are sparse. For example, a recent study (Kurihara *et al.*, 1999) observed Y_m values outside the ranges described in Table 10.12.

TABLE 10.12
CATTLE/BUFFALO CH_4 CONVERSION FACTORS (Y_M)

Livestock category	Y_m [b]
Feedlot fed Cattle [a]	3.0% $\pm$ 1.0%
Dairy Cows (Cattle and Buffalo) and their young	6.5% $\pm$ 1.0%
Other Cattle and Buffaloes that are primarily fed low quality crop residues and by-products	6.5% $\pm$ 1.0%
Other Cattle or Buffalo – grazing	6.5% $\pm$ 1.0%

[a] When fed diets contain 90 percent or more concentrates.

[b] The ± values represent the range.

Source: IPCC Expert Group.

Regional, national and global estimates of enteric methane generation rely on small scale determinations both of Y_m and of the influence of feed and animal properties upon Y_m. Traditional methods for measuring Y_m include the use of respiration calorimeters for housing individual animals (Johnson and Johnson, 1995). A tracer technique using SF_6 enables methane emissions from individual animals to be estimated under both housed or grazing conditions (Johnson *et al.*, 1994). The results of recent measurements have been surveyed by Lassey (2006) who also examines the "upscaling" of such measurements to national and global inventories.

It is also important to examine the influences of feed properties and animal attributes on Y_m. Such influences are important to better understand the microbiological mechanisms involved in methanogenesis with a view to designing emission abatement strategies, as well as to identify different values for Y_m according to animal husbandry practices. To date, the search for such influences is equivocal, and consequently there is little variability evident both in the values reported in Table 10.12 as supported by the recent survey of Y_m measurements in the literature (Lassey, 2006).

Table 10.13 proposes a common Y_m value for all mature sheep irrespective of feed quality, but with different values for mature and juvenile sheep with demarcation at 1 year of age. These values are based on data by Lassey *et al.* (1997), Judd *et al.* (1999) and Ulyatt *et al.* (2002a, 2002b, 2005) and while consistent with measurements by other researchers (Murray *et al.*, 1978; Leuning *et al.*, 1999), may not span the full range of pastures to be found. The median value is appropriate for most applications, but for poor quality feed the upper limits may be more appropriate, and for high-digestibility high-energy feeds the lower limits may be used.

TABLE 10.13
SHEEP CH_4 CONVERSION FACTORS (Y_M)

Category	**Y_m** [a]
Lambs (<1 year old)	4.5% ± 1.0%
Mature Sheep	6.5% ± 1.0%

[a] The ± values represent the range.

Note that in some cases, CH_4 conversion factors may not exist for specific livestock types. In these instances, CH_4 conversion factors from the reported livestock that most closely resembles those livestock types can be reported. For examples, CH_4 conversion factors for other cattle or buffalo could be applied to estimate an emission factor for camels.

2. Emission factor development

An emission factor for each animal category should be developed following Equation 10.21:

EQUATION 10.21
CH_4 EMISSION FACTORS FOR ENTERIC FERMENTATION FROM A LIVESTOCK CATEGORY

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

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

This emission factor equation assumes that the emission factors are being developed for an animal category for an entire year (365 days). While a full year emission factor is typically used, in some circumstances the animal category may be defined for a shorter period (e.g., for the wet season of the year or for a 150-day feedlot feeding period). In this case, the emission factor would be estimated for the specific period (e.g., the wet season) and the 365 days would be replaced by the number of days in the period. The definition of the period to which the emission factor applies is described in Section 10.2.

Step 3: Total emissions

To estimate total emissions, the selected emission factors are multiplied by the associated animal population and summed. As described above under Tier 1, the emissions estimates should be reported in gigagrams (Gg).

Potential for refinement of Tier 2 or development of a Tier 3 method to enteric methane emission inventories

Increased accuracy and identification of causes of variation in emissions are at the heart of inventory purpose. Improvements in country methodology, whether as components of current Tier 1 or 2 or if additional refinements are implemented (Tier 3), are encouraged.

Current Tier 1 and Tier 2 enteric methane emissions factors and estimation procedures are driven by first estimating daily and annual gross energy consumption by individual animals within an inventory class which are then multiplied by an estimate of CH_4 loss per unit of feed (Y_m). There is considerable room for improvement in

Tier 2 prediction of both feed intake and in Y_m. Factors potentially impacting feed requirements and/or consumption that are not considered include:

- breed or genotype variation in maintenance requirement;
- heat and cold stress effects on intake and maintenance requirements; and
- depression in digestibility with increasing levels of consumption, or diet composition limits to diet intake.

Likewise, a host of interacting factors that control variations in Y_m are not included in Tier 2 methodology, including:

- effects of digestibility (DE%);
- diet dry matter intake as it relates to live body weight;
- diet chemical composition;
- particle passage and digestion kinetics, or plant microbial defensive compounds; and
- variation in the microbial populations within the digestive tract.

Accurate estimation of diet DE% is singularly important in the estimation of feed intake and thus emissions, as previously emphasized. A 10% error in the average diet DE% or TDN% will result in CH_4 errors ranging from 12 to 20% depending on beginning circumstance. The depression in DE% with increasing daily amounts of diet consumed is not considered. This will underestimate feed intakes of high producing dairy cows consuming mixtures of concentrates and forages, e.g., as is common in the North America and Europe, although some of the resulting error in methane emission estimate will be compensated by reductions in Y_m as intake per day increases. Methods to estimate digestibility depressions have been described (NRC, 1996; NRC, 2001).

There have been many attempts to refine estimates of Y_m. Several researchers have developed models which relate the chemical composition of the diet consumed, or in more detail, the composition of digested carbohydrate and other chemical components to Y_m. These models typically predict diet particle and chemical component rates of passage and digestion in each enteric compartment at varying intake and the resulting H_2 balance, volatile fatty acids, and microbial and CH_4 yields. These approaches have generated Y_m values that are consistent with direct measurements using chamber and SF_6 techniques.

The literature contains many examples of the positive relationship of plant cell wall digestion to high acetic to propionic end-product ratios, and to high CH_4 yields. While fibrous carbohydrate digestion is undeniably the strongest single indicator of CH_4 yield, the CH_4 per digested fiber is not constant, e.g., when soyhulls or beet pulp are fed as single feed at varying levels of intake, Y_m will vary from 8 to 11% when measured at restricted feed intakes and from 5 to 6% when measure at ad libitum intakes (Kujawa, 1994; Diarra, 1994). Thus, enteric fermentation of the same fibrous substrate can result in quite different Y_m values. Perhaps the most severe limitation to development of more complex prediction models lies in the difficulty of applying them to broad country inventories. The difficulty is to provide the data needed to drive these more complex models of feed intake or Y_m. It is often difficult to define animal characteristics, productivity, and %DE accurately for a class of livestock in a region of the country, let alone detailed carbohydrate fraction, rates of passage and digestion, etc.

The amount of global research on mitigation strategies currently going on, such as vaccines, ionophores, polyunsaturated vegetable oils, condensed tannins etc, suggests a need to address how they should be reflected in inventory compilation at Tier 2 or Tier 3. First, the inventory should reflect only those technologies that conform to QA/QC principles and have attracted a wide degree of international acceptance such as through peer-reviewed articles that include a description of the technology, its efficacy and its validation under field conditions. Second, the inventory should be accompanied by evidence of the take-up of the technology, and apply it only to emissions by those livestock where take-up can be validated. Third, for a newly implemented technology (such as an administered dose of a mitigating agent), the inventory could also present an accompanying calculation of the emissions in the absence of a mitigation measure in order to make transparent the magnitude of the emission reductions that are being claimed. Mitigation measures should be supported by peer-reviewed publications.

Approaches to improve estimates of feed intake and Y_m and to consider mitigation approaches are to be encouraged, given due care on limitations of scope, production circumstance, etc. to which the predictive relationships apply.

10.3.3 Choice of activity data

Livestock population data should be obtained using the approach described in Section 10.2. If using default enteric emission factors for livestock (Tables 10.10, 10.11) to estimate enteric emissions, a basic (Tier 1) livestock population characterisation is sufficient. To estimate enteric emissions from livestock using estimation of Gross Energy Intake (Equations 10.16, 10.17 or 10.18), a Tier 2 characterisation is needed. As noted in Section 10.2, *good practice* in characterising livestock populations is to conduct a single characterisation that will provide the activity data for all emissions sources that depend on livestock population data.

10.3.4 Uncertainty assessment

Emission factors

As the emission factors for the Tier 1 method are not based on country-specific data, they may not accurately represent a country's livestock characteristics, and may be highly uncertain as a result. Emission factors estimated using the Tier 1 method are unlikely to be known more accurately than ±30% and may be uncertain to ±50%. The uncertainty under the Tier 2 method will depend on the accuracy of the livestock characterisation (e.g., homogeneity of livestock categories), and also on the extent to which the methods for defining the coefficients in the various relationships that make up the net energy approach correspond to national circumstances. Emission factor estimates using the Tier 2 method are likely to be in the order of ±20%. Inventory compilers using the Tier 2 method should undertake an analysis of uncertainties reflecting their particular situation, and in the absence of this analysis the uncertainty under the Tier 2 method should be assumed similar to the uncertainty under the Tier 1 method.

Although a Tier 3 method has the potential to improve the accuracy of emission estimates, a substantial body of scientific data is required to develop a viable Tier 3 method. The use of unreliable and unsubstantiated data in a Tier 3 method could result in estimates that are inferior to Tier 2 or even Tier 1 methods. In many instances, direct measurements of methane emissions from livestock are lacking or have been conducted using a limited number of diet types. A considerable amount of research on potential mitigation strategies is ongoing, but few of these have been validated to the point that they can be extrapolated to non-research conditions. As the foundational research on emission related science continues to expand, Tier 3 method should theoretically result in the lowest degree of uncertainty.

Activity data

There will be an added uncertainty associated with the livestock and feed characterisation. Improving the livestock and feed characterisation will often be the priority in reducing overall uncertainty. Accurate estimates of feed digestibility (DE%) are also critical for reducing the degree of uncertainty. Uncertainty estimates can be derived from the *good practice* approach to agricultural census data outlined in the uncertainty section for livestock and feed characterisation (see Section 10.2).

General information on the procedures to assess uncertainty is presented in Volume 1, Chapter 3 (Uncertainties).

10.3.5 Completeness, Time series, Quality Assurance/Quality Control and Reporting

To achieve completeness, all the major animal categories managed in the country should be considered. In the event that animals are included in the inventory for which default data are not available and for which no guidelines are provided, the emissions estimate should be developed using the same general principles presented in the discussion in Section 10.2.

Care must be taken to use a consistent set of estimates for the CH_4 conversion factors over time. In some cases, there may be reasons to modify methane conversion factors over time. These changes may be due to the implementation of explicit greenhouse gas (GHG) mitigation measures, or may be due to changing agricultural practices such as feed conditions or other management factors without regard to GHGs. Regardless of the driver of change, the data and methane conversion factors used to estimate emissions must reflect the change in farm practices. If methane conversion factors over a time series are affected by a change in management practice and/or the implementation of GHG mitigation measures, the inventory compiler should ensure that the inventory data reflect these practices. The inventory text should thoroughly explain how the changes in management practice and/or implementation of mitigation measures has affected the time series of methane conversion factors. For general *good practice* guidance on developing a consistent time series, see Volume 1, Chapter 5 (Time Series Consistency).

It is *good practice* to implement quality control checks as outlined in Volume 1, Chapter 6 (Quality Assurance/Quality Control and Verification). In addition to the guidance in Volume 1, specific procedures of relevance to this source category are outlined below:

Activity data check

- The inventory compiler should review livestock data collection methods, in particular checking that livestock subspecies data were collected and aggregated correctly. The data should be cross-checked with previous years to ensure the data are reasonable and consistent with the expected trend. Inventory compilers should document data collection methods, identify potential areas of bias, and evaluate the representativeness of the data. Population modeling can be used to support this approach.

Review of emission factors

- If using the Tier 2/Tier 3 method, the inventory compiler should cross-check country-specific factors against the IPCC defaults. Significant differences between country-specific factors and default factors should be explained and documented.

External review

- If Tier 2/Tier 3 method is used, the inventory compiler is encouraged to conduct national and international expert review, including from industry, academic institutions, and extension expertise.
- It is important to maintain internal documentation on review results.

To improve transparency, emission estimates from this source category should be reported along with the activity data and emission factors used to determine the estimates.

The following information should be documented:

- All activity data including animal population data by category and region.
- Activity data documentation including:
    (i) The sources of all activity data used in the calculations (i.e., complete citation for the statistical database from which data were collected);
    (ii) The information and assumptions that were used to develop the activity data, in cases where activity data were not directly available from databases; and
    (iii) The frequency of data collection, and estimates of accuracy and precision.
- If Tier 1 method is used, all default emission factors used in the estimation of emissions for the specific animal categories.
- If Tier 2 method is used:
    (i) Values for Y_m;
    (ii) DE values estimated or taken from other studies; and
    (iii) Full documentation of the data used including their references.
- For inventories in which country- or region-specific emission factors are used or in which new methods, such as Tier 3 are used, the scientific basis of these emission factors and the principles of the new method should be thoroughly documented. Documentation should include definitions of input parameters and a description of the principle and process by which these emission factors and methods are derived, as well as describing sources and magnitudes of uncertainties.

10.4 METHANE EMISSIONS FROM MANURE MANAGEMENT

This section describes how to estimate CH_4 produced during the storage and treatment of manure, and from manure deposited on pasture. The term 'manure' is used here collectively to include both dung and urine (i.e., the solids and the liquids) produced by livestock. The emissions associated with the burning of dung for fuel are to be reported under Volume 2 (Energy), or under Volume 5 (Waste) if burned without energy recovery. The decomposition of manure under anaerobic conditions (i.e., in the absence of oxygen), during storage and treatment, produces CH_4. These conditions occur most readily when large numbers of animals are managed in a confined area (e.g., dairy farms, beef feedlots, and swine and poultry farms), and where manure is disposed of in liquid-based systems. Emissions of CH_4 related to manure handling and storage are reported under 'Manure Management.'

The main factors affecting CH_4 emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically. The former depends on the rate of waste production per animal and the number of animals, and the latter on how the manure is managed. When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it decomposes anaerobically and can produce a significant quantity of CH_4. The temperature and the retention time of the storage unit greatly affect the amount of methane produced. When manure is handled as a solid (e.g., in stacks or piles) or when it is deposited on pastures and rangelands, it tends to decompose under more aerobic conditions and less CH_4 is produced.

10.4.1 Choice of method

There are three tiers to estimate CH_4 emissions from livestock manure. Guidance for determining which tier to use is shown in Figure 10.3 decision tree.

Tier 1
A simplified method that only requires livestock population data by animal species/category and climate region or temperature, in combination with IPCC default emission factors, to estimate emissions. Because some emissions from manure management systems are highly temperature dependent, it is *good practice* to estimate the average annual temperature associated with the locations where manure is managed.

Tier 2
A more complex method for estimating CH_4 emissions from manure management should be used where a particular livestock species/category represents a significant share of a country's emissions. This method requires detailed information on animal characteristics and manure management practices, which is used to develop emission factors specific to the conditions of the country.

Tier 3
Some countries for which livestock emissions are particularly important may wish to go beyond the Tier 2 method and develop models for country-specific methodologies or use measurement–based approaches to quantify emission factors.

The method chosen will depend on data availability and national circumstances. *Good practice* in estimating CH_4 emissions from manure management systems entails making every effort to use the Tier 2 method, including calculating emission factors using country-specific information. The Tier 1 method should only be used if all possible avenues to use the Tier 2 method have been exhausted and/or it is determined that the source is not a key category or subcategory.

Regardless of the method chosen, the animal population must first be divided into categories as described in Section 10.2 that reflect the varying amounts of manure produced per animal.

The following four steps are used to estimate CH_4 emissions from manure management:

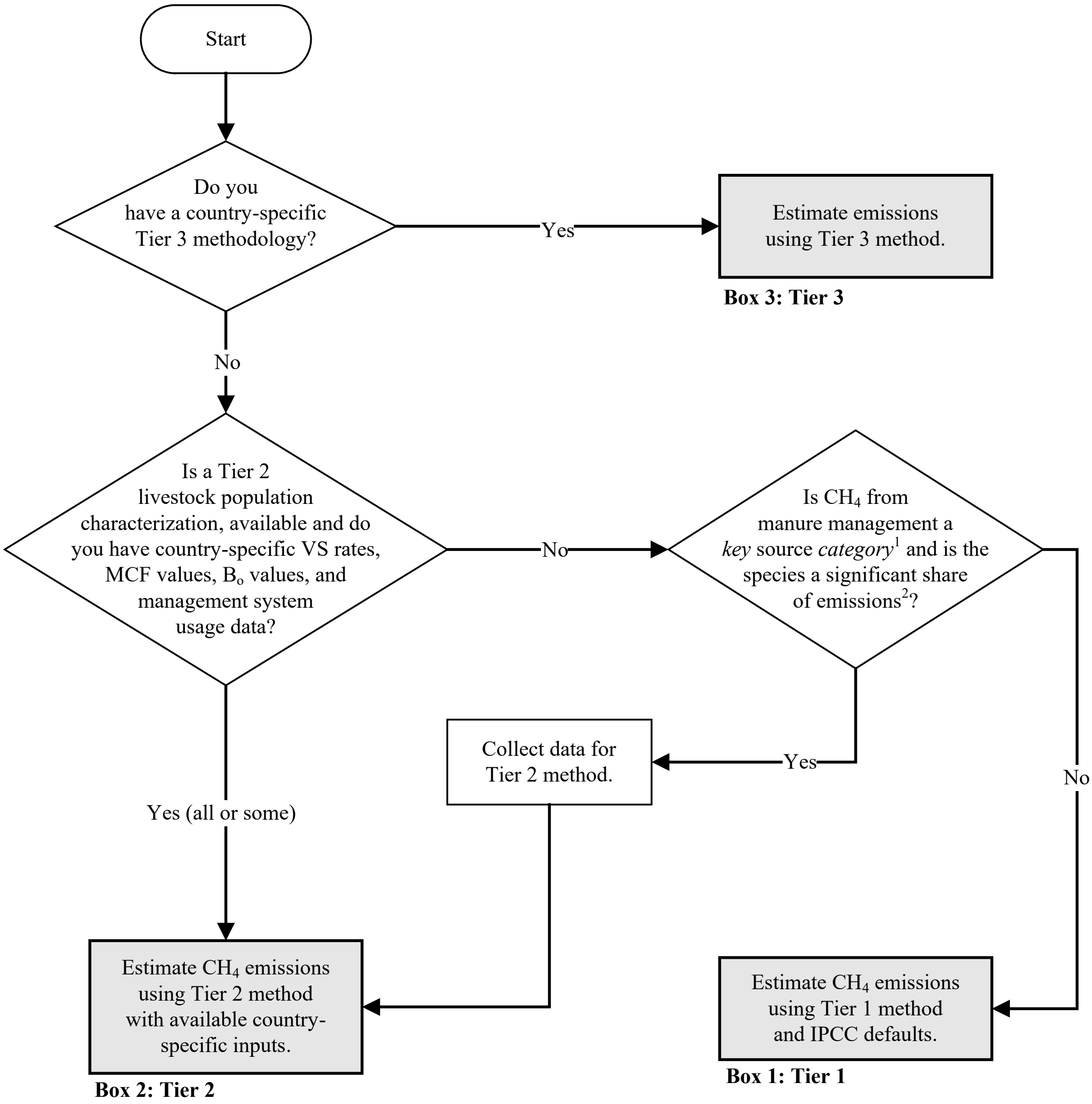
Step 1: Collect population data from the Livestock Population Characterisation (see Section 10.2).

Step 2: Use default values or develop country-specific emission factors for each livestock subcategory in terms of kilograms of methane per animal per year.

Step 3: Multiply the livestock subcategory emission factors by the subcategory populations to estimate subcategory emissions, and sum across the subcategories to estimate total emissions by primary livestock species.

Step 4: Sum emissions from all defined livestock species to determine national emissions.

Figure 10.3 Decision tree for CH_4 emissions from Manure Management



Note:
1: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.
2: As a rule of thumb, a livestock species would be significant if it accounts for 25-30% or more of emissions from the source category.

Equation 10.22 shows how to calculate CH_4 emissions from manure management:

EQUATION 10.22
CH_4 EMISSIONS FROM MANURE MANAGEMENT

$$CH_{4\,Manure} = \sum_{(T)} \frac{\left(EF_{(T)} \bullet N_{(T)}\right)}{10^6}$$

Where:

$CH_{4Manure}$ = CH_4 emissions from manure management, for a defined population, Gg CH_4 yr^{-1}

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4 $head^{-1}$ yr^{-1}

$N_{(T)}$ = the number of head of livestock species/category *T* in the country

T = species/category of livestock

10.4.2 Choice of emission factors

The best way to determine emission factors is to conduct non-invasive or non-disturbing measurements of emissions in actual systems representative of those in use in the country. These field results can be used to develop models to estimate emission factors (Tier 3). Such measurements are difficult to conduct, and require significant resources and expertise, and equipment that may not be available. Thus, while such an approach is recommended to improve accuracy, it is not required for *good practice*. This section provides two alternatives for developing emission factors, with the selection of emission factors depending on the method (i.e., Tier 1 or Tier 2) chosen for estimating emissions.

Tier 1

When using the Tier 1 method, methane emission factors by livestock category or subcategory are used. Default emission factors by average annual temperature are presented in Table 10.14, Table 10.15, and Table 10.16 for each of the recommended population subcategories. These emission factors represent the range in manure volatile solids content and in manure management practices used in each region, as well as the difference in emissions due to temperature. Tables 10A-4 through 10A-9 located in Annex 10A.2 present the underlying assumptions used for each region. Countries using a Tier 1 method to estimate methane emissions from manure management should review the regional variables in these tables to identify the region that most closely matches their animal operations, and use the default emission factors for that region.

Table 10.14 shows the default emission factors for cattle, swine, and buffalo for each region and temperature classification. Emission factors are listed by the annual average temperature for the climate zone where the livestock manure is managed. The temperature data should be based on national meteorological statistics where available. Countries should estimate the percentage of animal populations in different temperature zones and compute a weighted average emission factor. Where this is not possible, the annual average temperature for the entire country could be utilized; however, this may not give an accurate estimate of emissions that are highly sensitive to temperature variations (e.g., liquid/slurry systems).

Tables 10.15 and 10.16 present the default manure management emission factors for other animal species. Separate emission factors are shown for developed and developing countries in Table 10.15, reflecting the general differences in feed intake and feed characteristics of the animals in the two regions. Except for poultry "layers (wet)," 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).

TABLE 10.14
MANURE MANAGEMENT METHANE EMISSION FACTORS BY TEMPERATURE FOR CATTLE, SWINE, AND BUFFALO[a]
(KG CH_4 HEAD^{-1} YR^{-1})

Regional characteristics	Livestock species	CH_4 emission factors by average annual temperature (°C)[b]																		
		Cool					Temperate											Warm		
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28
North America: Liquid-based systems are commonly used for dairy cows and swine manure. Other cattle manure is usually managed as a solid and deposited on pastures or ranges.	Dairy Cows	48	50	53	55	58	63	65	68	71	74	78	81	85	89	93	98	105	110	112
	Other Cattle	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Market Swine	10	11	11	12	12	13	13	14	15	15	16	17	18	18	19	20	22	23	23
	Breeding Swine	19	20	21	22	23	24	26	27	28	29	31	32	34	35	37	39	41	44	45
Western Europe: Liquid/slurry and pit storage systems are commonly used for cattle and swine manure. Limited cropland is available for spreading manure.	Dairy Cows	21	23	25	27	29	34	37	40	43	47	51	55	59	64	70	75	83	90	92
	Other Cattle	6	7	7	8	8	10	11	12	13	14	15	16	17	18	20	21	24	25	26
	Market Swine	6	6	7	7	8	9	9	10	11	11	12	13	14	15	16	18	19	21	21
	Breeding Swine	9	10	10	11	12	13	14	15	16	17	19	20	22	23	25	27	29	32	33
	Buffalo	4	4	5	5	5	6	7	7	8	9	9	10	11	12	13	14	15	16	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 Cows	11	12	13	14	15	20	21	22	23	25	27	28	30	33	35	37	42	45	46
	Other Cattle	6	6	7	7	8	9	10	11	11	12	13	14	15	16	18	19	21	23	23
	Market Swine	3	3	3	3	3	4	4	4	4	5	5	5	6	6	6	7	10	10	10
	Breeding Swine	4	5	5	5	5	6	7	7	7	8	8	9	9	10	11	12	16	17	17
	Buffalo	5	5	5	6	6	7	8	8	9	10	11	11	12	13	15	16	17	19	19
Oceania: Most cattle manure is managed as a solid on pastures and ranges, except dairy cows where there is some usage of lagoons. About half of the swine manure is managed in anaerobic lagoons.	Dairy Cows	23	24	25	26	26	27	28	28	28	29	29	29	29	29	30	30	31	31	31
	Other Cattle	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Market Swine	11	11	12	12	12	13	13	13	13	13	13	13	13	13	13	13	13	13	13
	Breeding Swine	20	20	21	21	22	22	23	23	23	23	23	24	24	24	24	24	24	24	24
Latin America: Almost all livestock manure is managed as a solid on pastures and ranges. Buffalo manure is deposited on pastures and ranges.	Dairy Cows	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
	Other Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
	Buffalo	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2

TABLE 10.14
MANURE MANAGEMENT METHANE EMISSION FACTORS BY TEMPERATURE FOR CATTLE, SWINE, AND BUFFALO[a]
(KG CH_4 HEAD^{-1} YR^{-1})

Regional characteristics	Livestock species	CH_4 emission factors by average annual temperature (°C)[b]																		
		Cool					Temperate											Warm		
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28
Africa: Most livestock manure is managed as a solid on pastures and ranges. A smaller, but significant fraction is burned as fuel.	Dairy Cows	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Other Cattle	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	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 Cows	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3
	Other Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	1	1	1	2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6
	Buffalo	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	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 Cows	9	10	10	11	12	13	14	15	16	17	18	20	21	23	24	26	28	31	31
	Other Cattle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Swine	2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6	6	7	7
	Buffalo	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
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 Cows	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	6
	Other Cattle	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Swine	2	2	3	3	3	3	3	3	4	4	4	4	4	5	5	5	6	6	6
	Buffalo	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Source: See Annex 10A.2 , Tables 10A-4 to 10A-8 for derivation of these emission factors,

The uncertainty in these emission factors is ±30 %.

[a] When selecting a default emission factor, be sure to consult the supporting tables in Annex 10A.2 for the distribution of manure management systems and animal waste characteristics used to estimate emissions. Select an emission factor for a region that most closely matches your own in these characteristics.

[b] All temperatures 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.

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

TABLE 10.15
MANURE MANAGEMENT METHANE EMISSION FACTORS BY TEMPERATURE FOR SHEEP, GOATS, CAMELS, HORSES, MULES AND ASSES, AND POULTRY[a] (KG CH_4 HEAD^{-1} YR^{-1})

Livestock	**CH_4 emission factor by average annual temperature (°C)**		
	Cool (<15˚C)	**Temperate (15 to 25˚C)**	**Warm (>25˚C)**
Sheep			
Developed countries	0.19	0.28	0.37
Developing countries	0.10	0.15	0.20
Goats			
Developed countries	0.13	0.20	0.26
Developing countries	0.11	0.17	0.22
Camels			
Developed countries	1.58	2.37	3.17
Developing countries	1.28	1.92	2.56
Horses			
Developed countries	1.56	2.34	3.13
Developing countries	1.09	1.64	2.19
Mules and Asses			
Developed countries	0.76	1.10	1.52
Developing countries	0.60	0.90	1.20
Poultry			
Developed countries			
Layers (dry)[b]	0.03	0.03	0.03
Layers (wet)[c]	1.2	1.4	1.4
Broilers	0.02	0.02	0.02
Turkeys	0.09	0.09	0.09
Ducks	0.02	0.03	0.03
Developing countries	0.01	0.02	0.02

The uncertainty in these emission factors is ±30 %.

Sources: Emission factors developed from: feed intake values and feed digestibilities used to develop the enteric fermentation emission factors (see Annex 10A.1); Except for poultry in developed countries, methane conversion factor (MCF), and maximum methane producing capacity (B_o) values reported in Woodbury and Hashimoto (1993). Poultry for developed countries was subdivided into five categories. Layers (dry) represent layers in a "without bedding" waste management system; layers (wet) represent layers in an anaerobic lagoon waste management system. For layers, volatile solids (VS) are values reported in USDA (1996); typical animal mass values are from ASAE (1999); and B_o values for Layers are values reported by Hill (1982). For broilers and turkeys, B_o values are from Hill (1984); typical animal mass values are from ASAE (1999); and VS values are those reported in USDA (1996). B_o values for ducks were transferred from broilers and turkeys; typical animal mass values are from MWPS-18; and VS values are from USDA, AWMFH. Typical mass of sheep, goats and horses, and VS and B_o values of goats and horses for developed countries updated according to the analysis of GHG inventories of Annex I countries. All manure, with the exception of Layers (wet), is assumed to be managed in dry systems, which is consistent with the manure management system usage reported in Woodbury and Hashimoto (1993).

[a] When selecting a default emission factor, be sure to consult the supporting tables in Annex 10A.2 for the distribution of manure management systems and animal waste characteristics used to estimate emissions. Select an emission factor for a region that most closely matches your own in these characteristics.

[b] Layer operations that manage dry manure.

[c] Layer operations that manage manure as a liquid, such as stored in an anaerobic lagoon.

TABLE 10.16
MANURE MANAGEMENT METHANE EMISSION FACTORS FOR DEER, REINDEER, RABBITS, AND FUR-BEARING ANIMALS

Livestock	**CH_4 emission factor (kg CH_4 head^{-1} yr^{-1})**
Deer[a]	0.22
Reindeer[b]	0.36
Rabbits[c]	0.08
Fur-bearing animals (e.g., fox, mink)[b]	0.68

The uncertainty in these emission factors is ±30 %.

[a] Sneath *et al.* (1997)

[b] Estimations of Agricultural University of Norway, Institute of Chemistry and Biotechnology, Section for Microbiology.

[c] Judgement of the IPCC Expert Group

Tier 2

The Tier 2 method is applicable when Manure Management is a key source or when the data used to develop the default values do not correspond well with the country's livestock and manure management conditions. Because cattle, buffalo and swine characteristics and manure management systems can vary significantly by country, countries with large populations of these animals should consider using the Tier 2 method for estimating methane emissions. The Tier 2 method relies on two primary types of inputs that affect the calculation of methane emission factors from manure:

Manure characteristics*:* Includes the amount of volatile solids (VS) produced in the manure and the maximum amount of methane able to be produced from that manure (B_o). Production of manure VS can be estimated based on feed intake and digestibility, which are the variables also used to develop the Tier 2 enteric fermentation emission factors. Alternatively, VS production rates can be based on laboratory measurements of livestock manure. B_o varies by animal species and feed regimen and is a theoretical methane yield based on the amount of VS in the manure. Bedding materials (straw, sawdust, chippings, etc.) are not included in the VS modelled under the Tier 2 method. The type and use of these materials is highly variable from country to country. Since they typically are associated with solid storage systems, their contribution would not add significantly to overall methane production.

Manure management system characteristics*:* Includes the types of systems used to manage manure and a system-specific methane conversion factor (MCF) that reflects the portion of B_o that is achieved. Regional assessments of manure management systems are used to estimate the portion of the manure that is handled with each manure management technique. A description of manure management systems is included in Table 10.18. The system MCF varies with the manner in which the manure is managed and the climate, and can theoretically range from 0 to 100%. Both temperature and retention time play an important role in the calculation of the MCF. Manure that is managed as a liquid under warm conditions for an extended period of time promotes methane formation. These manure management conditions can have high MCFs, of 65 to 80%. Manure managed as dry material in cold climates does not readily produce methane, and consequently has an MCF of about 1%.

Development of Tier 2 emission factors involves determining a weighted average MCF using the estimates of the manure managed by each waste system within each climate region. The average MCF is then multiplied by the VS excretion rate and the B_o for the livestock categories. In equation form, the estimate is as follows:

EQUATION 10.23
CH_4 EMISSION FACTOR FROM MANURE MANAGEMENT

$$EF_{(T)} = \left(VS_{(T)} \bullet 365\right) \bullet \left[B_{o(T)} \bullet 0.67\, kg/m^3 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet MS_{(T,S,k)} \right]$$

Where:

$EF_{(T)}$ = annual CH_4 emission factor for livestock category *T*, kg CH_4 animal^{-1} yr^{-1}

$VS_{(T)}$ = daily volatile solid excreted for livestock category *T*, kg dry matter animal^{-1} day^{-1}

365 = basis for calculating annual VS production, days yr^{-1}

$B_{o(T)}$ = maximum methane producing capacity for manure produced by livestock category *T*, m^3 CH_4 kg^{-1} of VS excreted

0.67 = conversion factor of m^3 CH_4 to kilograms CH_4

$MCF_{(S,k)}$ = methane conversion factors for each manure management system *S* by climate region *k*, %

$MS_{(T,S,k)}$ = fraction of livestock category *T*'s manure handled using manure management system *S* in climate region *k*, dimensionless

Even when the level of detail presented in the Tier 2 method is not possible in some countries, country-specific data elements such as animal mass, VS excretion, and others can be used to improve emission estimates. If country-specific data are available for only a portion of these variables, countries are encouraged to calculate country-specific emission factors, using the data in Tables 10A-4 through 10A-9 to fill gaps.

Measurement programs can be used to improve the basis for making the estimates. In particular, measurements of emissions from manure management systems under field conditions are useful to verify MCFs. Also, measurements of B_o from livestock in tropical regions and for varying diet regimens are needed to expand the representativeness of the default factors.

As emissions can vary significantly by region and livestock species/category, emission estimates should reflect as much as possible the diversity and range of animal populations and manure management practices between different regions within a country. This may require separate estimates to be developed for each region. Emission factors should be updated periodically to account for changes in manure characteristics and management practices. These revisions should be based on reliable scientifically reviewed data. Frequent monitoring is desirable to verify key model parameters and to track changing trends in the livestock industry.

VS excretion rates

Volatile solids (VS) are the organic material in livestock manure and consist of both biodegradable and non-biodegradable fractions. The value needed for the Equation 10.23 is the total VS (both degradable and non-biodegradable fractions) as excreted by each animal species since the B_o values are based on total VS entering the systems. The best way to obtain average daily VS excretion rates is to use data from nationally published sources. If average daily VS excretion rates are not available, country-specific VS excretion rates can be estimated from feed intake levels. Feed intake for cattle and buffalo can be estimated using the 'Enhanced' characterisation method described in Section 10.2. This will also ensure consistency in the data underlying the emissions estimates. For swine, country-specific swine production data may be required to estimate feed intake.

The VS content of manure equals the fraction of the diet consumed that is not digested and thus excreted as fecal material which, when combined with urinary excretions, constitutes manure. Countries should estimate gross energy (GE) intake (Section 10.2, Equation 10.16) and its fractional digestibility, DE, in the process of estimating enteric methane emissions.

Once these are estimated, the VS excretion rate is estimated as:

EQUATION 10.24
VOLATILE SOLID EXCRETION RATES

$$VS = \left[GE \bullet \left(1 - \frac{DE\%}{100} \right) + \left(UE \bullet GE \right) \right] \bullet \left[\left(\frac{1 - ASH}{18.45} \right) \right]$$

Where:

VS = volatile solid excretion per day on a dry-organic matter basis, kg VS day^{-1}

GE = gross energy intake, MJ day^{-1}

DE% = digestibility of the feed in percent (e.g. 60%)

(UE • GE) = urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). Use country-specific values where available.

ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle). Use country-specific values where available.

18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

Representative DE% values for various livestock categories are provided in Section 10.2, Table 10.2 of this report. The value for ash content fraction can range substantially between livestock types and should reflect national circumstances.

B_o values

The maximum methane-producing capacity of the manure (B_o) varies by species and diet. The preferred method to obtain B_o measurement values is to use data from country-specific published sources, measured with a standardised method. It is important to standardise the B_o measurement, including the method of sampling, and to confirm if the value is based on total as-excreted VS or biodegradable VS, since the Tier 2 calculation is based on total as-excreted VS. If country-specific B_o measurement values are not available, default values are provided in Tables 10A-4 through 10A-9.

MCFs

Default methane conversion factors (MCFs) are provided in Table 10.17 for different manure management systems and by annual average temperatures. MCFs are determined for a specific manure management system and represent the degree to which B_o is achieved. The amount of methane generated by a specific manure management system is affected by the extent of anaerobic conditions present, the temperature of the system, and the retention time of organic material in the system. Default MCF values for lagoons presented in Table 10.17 include the effect of longer retention times, and as a result, are higher than other systems under most circumstances.

Since liquid-based systems are very sensitive to temperature effects, where possible default MCF values for these systems have been presented in Table 10.17 for specific annual average temperatures in each climate range. While these temperature ranges should cover most climate conditions, areas that have extreme high or low annual average temperatures outside the 10 to 28 degree Celsius range should utilize the end-of-range (i.e., 10 or 28 degree) values or investigate developing country-specific values.

These default values may not encompass the potentially wide variation within the defined categories of management systems. Therefore, country-specific MCFs that reflect the specific management systems used in particular countries or regions should be developed if possible. This is particularly important for countries with large animal populations or with multiple climate regions. In such cases, and if possible, field measurements should be conducted for each climate region to replace the default MCF values. Measurements should include the following factors:

- Timing of storage/application;
- Feed and animal characteristics at the measurement site (see Section 10.2 for the type of data that would be pertinent);
- Length of storage;
- Manure characteristics (e.g., VS influent and effluent concentrations for liquid systems);
- Determination of the amount of manure left in the storage facility (methanogenic inoculum);
- Time and temperature distribution between indoor and outdoor storage;
- Daily temperature fluctuation; and
- Seasonal temperature variation.

TABLE 10.17
MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS

System[a]		MCFs by average annual temperature (°C)																			Source and comments
		Cool					Temperate											Warm			
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Pasture/Range/Paddock		1.0%					1.5%											2.0%			Judgement of IPCC Expert Group in combination with Hashimoto and Steed (1994).
Daily spread		0.1%					0.5%											1.0%			Hashimoto and Steed (1993).
Solid storage		2.0%					4.0%											5.0%			Judgement of IPCC Expert Group in combination with Amon *et al.* (2001), which shows emissions of approximately 2% in winter and 4% in summer. Warm climate is based on judgement of IPCC Expert Group and Amon *et al.* (1998).
Dry lot		1.0%					1.5%											2.0%			Judgement of IPCC Expert Group in combination with Hashimoto and Steed (1994).
Liquid/Slurry	With natural crust cover	10%	11%	13%	14%	15%	17%	18%	20%	22%	24%	26%	29%	31%	34%	37%	41%	44%	48%	50%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001) and Sommer (2000). The estimated reduction due to the crust cover (40%) is an annual average value based on a limited data set and can be highly variable dependent on temperature, rainfall, and composition. When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to Formula 1.
	Without natural crust cover	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001). When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to Formula 1.

TABLE 10.17 (CONTINUED)
MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS

System[a]		MCFs by average annual temperature (°C)																			Source and comments
		Cool					Temperate											Warm			
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Uncovered anaerobic lagoon		66%	68%	70%	71%	73%	74%	75%	76%	77%	77%	78%	78%	78%	79%	79%	79%	79%	80%	80%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001). Uncovered lagoon MCFs vary based on several factors, including temperature, retention time, and loss of volatile solids from the system (through removal of lagoon effluent and/or solids).
Pit storage below animal confinements	< 1 month	3%					3%											30%			Judgement of IPCC Expert Group in combination with Moller *et al.* (2004) and Zeeman (1994). Note that the ambient temperature, not the stable temperature is to be used for determining the climatic conditions. When pits used as fed-batch storage/digesters, MCF should be calculated according to Formula 1.
	> 1 month	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001). Note that the ambient temperature, not the stable temperature is to be used for determining the climatic conditions. When pits used as fed-batch storage/digesters, MCF should be calculated according to Formula 1.

TABLE 10.17 (CONTINUED)
MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS

System[a]		**MCFs by average annual temperature (°C)**																			**Source and comments**
		Cool					**Temperate**											**Warm**			
		≤ 10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**≥ 28**	
Anaerobic digester		0-100%					0-100%											0-100%			Should be subdivided in different categories, considering amount of recovery of the biogas, flaring of the biogas and storage after digestion. Calculation with Formula 1.
Burned for fuel		10%					10%											10%			Judgement of IPCC Expert Group in combination with Safley *et al.* (1992).
Cattle and Swine deep bedding	< 1 month	3%					3%											30%			Judgement of IPCC Expert Group in combination with Moller *et al.* (2004). Expect emissions to be similar, and possibly greater, than pit storage, depending on organic content and moisture content.
Cattle and Swine deep bedding (cont.)	> 1 month	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001).
Composting - In-vessel[b]		0.5%					0.5%											0.5%			Judgement of IPCC Expert Group and Amon *et al.* (1998). MCFs are less than half of solid storage. Not temperature dependant.
Composting - Static pile[b]		0.5%					0.5%											0.5%			Judgement of IPCC Expert Group and Amon *et al.* (1998). MCFs are less than half of solid storage. Not temperature dependant.
Composting - Intensive windrow[b]		0.5%					1.0%											1.5%			Judgement of IPCC Expert Group and Amon *et al.* (1998). MCFs are slightly less than solid storage. Less temperature dependant.
Composting – Passive windrow[b]		0.5%					1.0%											1.5%			Judgement of IPCC Expert Group and Amon *et al.* (1998). MCFs are slightly less than solid storage. Less temperature dependant.

TABLE 10.17 (CONTINUED)
MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS

System[a]	MCFs by average annual temperature (°C)																			Source and comments
	Cool					Temperate											Warm			
	≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Poultry manure with litter	1.5%					1.5%											1.5%			Judgement of IPCC Expert Group. MCFs are similar to solid storage but with generally constant warm temperatures.
Poultry manure without litter	1.5%					1.5%											1.5%			Judgement of IPCC Expert Group. MCFs are similar to dry lot at a warm climate.
Aerobic treatment	0%					0%											0%			MCFs are near zero. Aerobic treatment can result in the accumulation of sludge which may be treated in other systems. Sludge requires removal and has large VS values. It is important to identify the next management process for the sludge and estimate the emissions from that management process if significant.

Formula 1 (Timeframe for inputs should reflect operating period of digester):

$$MCF = [\{CH_4\ prod - CH_4\ used - CH_4\ flared + (MCF_{storage} / 100 * B_o * VS_{storage} * 0.67)\} / (B_o * VS_{storage} * 0.67)] * 100$$

Where:

CH_4 prod = methane production in digester , (kg CH_4) . Note: When a gas tight coverage of the storage for digested manure is used, the gas production of the storage should be included.

CH_4 used = amount of methane gas used for energy, (kg CH_4)

CH_4 flared = amount of methane flared, (kg CH_4)

$MCF_{storage}$ = MCF for CH_4 emitted during storage of digested manure (%)

$VS_{storage}$ = amount of VS excreted that goes to storage prior to digestion (kg VS)

When a gas tight storage is included: $MCF_{storage} = 0$; otherwise $MCF_{storage}$ = MCF value for liquid storage

[a] Definitions for manure management systems are provided in Table 10. 18.

[b] Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

10.4.3 Choice of activity data

There are two main types of activity data for estimating CH_4 emissions from manure management: (1) animal population data; and (2) manure management system usage data.

The animal population data should be obtained using the approach described in Section 10.2. As noted in Section 10.2, it is *good practice* to conduct a single livestock characterisation that will provide the activity data for all emissions sources relying on livestock population data. It is important to note, however, that the level of disaggregation in the livestock population data required to estimate emissions from manure management, may differ from those used for other sources, such as Enteric Fermentation. For example, for some livestock population species/categories, such as cattle, the enhanced characterisation required for the Tier 2 enteric fermentation estimate could be aggregated to broader categories that are sufficient for this source category. For other livestock species, such as swine, it may be preferable to have more disaggregation of weight categories for manure management calculations than for enteric fermentation. However, consistency in livestock categories should be retained throughout the inventory.

Inventory agencies in countries with varied climatic conditions are encouraged to obtain population data for each major climatic zone. In addition, where possible, the associated annual average temperature for locations where livestock manure is managed in liquid-based systems (e.g., pits, tanks, and lagoons) should be obtained. This will allow more specific selection of default factors or MCF values for those systems more sensitive to temperature changes. Ideally, the regional population breakdown can be obtained from published national livestock statistics, and the temperature data from national meteorological statistics. If regional data are not available, experts should be consulted regarding regional production (e.g., milk, meat, and wool) patterns or land distribution, which may provide the required information to estimate the regional animal distributions.

To implement the Tier 2 method, the portion of manure managed in each manure management system must also be collected for each representative animal species. Table 10.18 summarizes the main types of manure management systems. Quantitative data should be used to distinguish whether the system is judged to be a solid storage or liquid/slurry. The borderline between dry and liquid can be drawn at 20% dry matter content. Note that in some cases, manure may be managed in several types of manure management systems. For example, manure flushed from a dairy freestall barn to an anaerobic lagoon may first pass through a solids separation unit where some of the manure solids are removed and managed as a solid. Therefore, it is important to carefully consider the fraction of manure that is managed in each type of system.

The best means of obtaining manure management system distribution data is to consult regularly published national statistics. If such statistics are unavailable, the preferred alternative is to conduct an independent survey of manure management system usage. If the resources are not available to conduct a survey, experts should be consulted to obtain an opinion of the system distribution. Volume 1, Chapter 2 *Approaches to Data Collection* describes how to elicit expert judgement. Similar expert elicitation protocols can be used to obtain manure management system distribution data.

10.4.4 Uncertainty assessment

EMISSION FACTORS

There are large uncertainties associated with the default emission factors for Tier 1 (see Tables 10.14 to 10.16). The uncertainty range for the default factors is estimated to be ±30%. Improvements achieved by Tier 2 methodologies are estimated to reduce uncertainty ranges in the emission factors to ±20%. Accurate and well-designed emission measurements from well characterised types of manure and manure management systems can help reduce these uncertainties further. These measurements must account for temperature, moisture conditions, aeration, VS content, duration of storage, and other aspects of treatment.

The default values may have a large uncertainty for an individual country because they may not reflect the specific manure management conditions present within the country. Uncertainties can be reduced by developing and using MCF, B_o, and VS values that reflect country/region specific conditions.

TABLE 10.18
DEFINITIONS OF MANURE MANAGEMENT SYSTEMS

System	Definition
Pasture/Range/Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Solid storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically.
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
Uncovered anaerobic lagoon	A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields.
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.
Anaerobic digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4, which is captured and flared or used as a fuel.
Burned for fuel	The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel.
Cattle and Swine deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.
Composting - in-vessel[a]	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.
Composting - Static pile[a]	Composting in piles with forced aeration but no mixing.
Composting - Intensive windrow[a]	Composting in windrows with regular (at least daily) turning for mixing and aeration.
Composting - Passive windrow[a]	Composting in windrows with infrequent turning for mixing and aeration.
Poultry manure with litter	Similar to cattle and swine deep bedding except usually not combined with a dry lot or pasture. Typically used for all poultry breeder flocks and for the production of meat type chickens (broilers) and other fowl.
Poultry manure without litter	May be similar to open pits in enclosed animal confinement facilities or may be designed and operated to dry the manure as it accumulates. The latter is known as a high-rise manure management system and is a form of passive windrow composting when designed and operated properly.
Aerobic treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration. Natural aeration is limited to aerobic and facultative ponds and wetland systems and is due primarily to photosynthesis. Hence, these systems typically become anoxic during periods without sunlight.

[a] Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

ACTIVITY DATA – LIVESTOCK POPULATIONS

See Section 10.2 Livestock and Feed Characterisation for discussion on uncertainty of animal population and characterisation data.

ACTIVITY DATA – MANURE MANAGEMENT SYSTEM USAGE

The uncertainty of the manure management system usage data will depend on the characteristics of each country's livestock industry and how information on manure management is collected. For example, for countries that rely almost exclusively on one type of management system, such as pasture and range, the uncertainty associated with management system usage data can be 10% or less. However, for countries where there is a wide variety of management systems used with locally different operating practices, the uncertainty range in management system usage data can be much higher, in the range of 25% to 50%, depending on the availability of reliable and representative survey data that differentiates animal populations by system usage. Preferably, each country should estimate the uncertainty associated with their management system usage data by using the methods described in Volume 1, Chapter 3.

10.4.5 Completeness, Time series, Quality assurance / Quality control and Reporting

A complete inventory should estimate CH_4 emissions from all systems of manure management for all livestock species/categories identified in Section 10.2. Countries are encouraged to use manure management system definitions that are consistent with those presented in Table 10.18 to ensure that all types of systems are being accounted for. Population data should be cross-checked between main reporting mechanisms (such as FAO and national agricultural statistics databases) to ensure that information used in the inventory is complete and consistent. Because of the widespread availability of the FAO database of livestock information, most countries should be able to prepare, at a minimum, Tier 1 estimates for the major livestock categories. For more information regarding the completeness of livestock characterisation, see Section 10.2.

Developing a consistent time series of emission estimates for this source category requires, at a minimum, collection of an internally consistent time series of livestock population statistics. General guidance on the development of a consistent time series is addressed in Volume 1, Chapter 5 (Time Series Consistency).

If significant changes in manure management practices have occurred over time, the Tier 1 method will not provide an accurate time series of emissions (since the Tier 1 default factors are based on a historical set of parameters), and the Tier 2 method should be considered. When developing a time series for the Tier 2 method it is also necessary to collect country-specific manure management system data. In cases when manure management system data are not available for some period during the time series, trends can be used to extrapolate data from a sample area or region to the entire country, if climatic conditions are similar (i.e., temperature and rainfall). National livestock experts from government, industry, or universities should be consulted where possible to develop trends in management system usage and characteristics.

If the emission estimation method has changed, historical data that are required by the current method should be collected and used to recalculate emissions for that period. If such data are not available, it may be appropriate to create a trend with recent data and use the trend to back-estimate management practices for the time series. For example, it may be known that certain livestock industries are converting to more intensive management systems in lieu of grazing. Historically, this changeover should be captured in the time series of emissions, through modifications to the manure management system allocation. It may be necessary to base this allocation on expert judgment from national experts where extensive survey data are not available. Volume 1, Chapter 5 provides additional guidance on how to address recalculation issues. Also, Section 10.2 suggests approaches for the animal population aspects. The inventory text should thoroughly explain how the change in farm practices or implementation of mitigation measures has affected the time series of activity data or emission factors.

It is *good practice* to implement general quality control checks as outlined in Volume 1, Chapter 6, Quality Assurance/Quality Control and Verification, and expert review of the emission estimates. Additional quality control checks and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source. The general QA/QC related to data processing, handling, and reporting should be supplemented with procedures discussed below.

ACTIVITY DATA CHECK

- The inventory agency should review livestock data collection methods, in particular checking that livestock subspecies data were collected and aggregated correctly. The data should be cross-checked with previous years to ensure the data are reasonable and consistent with the expected trend. Inventory agencies should document data collection methods, identify potential areas of bias (e.g., systematic under-reporting of animal populations to statistical agencies by individual livestock owners), and evaluate the representativeness of the data.

- Manure management system allocation should be reviewed on a regular basis to determine if changes in the livestock industry are being captured. Conversion from one type of management system to another, and technical modifications to system configuration and performance, should be captured in the system modeling for the affected livestock.
- National agricultural policy and regulations may have an effect on parameters that are used to calculate manure emissions, and should be reviewed regularly to determine what impact they may have. For example, guidelines to reduce manure runoff into water bodies may cause a change in management practices, and thus affect the MCF value for a particular livestock category. Consistency should be maintained between the inventory and ongoing changes in agricultural practices.

REVIEW OF EMISSION FACTORS

- If using the Tier 1 method (using default IPCC emission factors), the inventory agency should evaluate how well the default VS excretion rates, B_o values, and manure management practices represent the defined animal population and manure characteristics of the country. This should be done by reviewing the background information from Tables 10A-4 to 10A-9 to see how well the default input parameters match the inventory area. If there is not a good match, substitution of more appropriate country-specific parameters can be used to develop an improved emission factor.
- If using the Tier 2 method, the inventory agency should cross-check the country-specific parameters (e.g., VS excretion rates, B_o, and MCF) against the IPCC defaults. Significant differences between country-specific parameters and default parameters should be explained and documented.
- If using the Tier 2 method, derivation of VS rates should be compared to background assumptions used for the enteric fermentation Tier 2 inventory where applicable. For example, the gross energy and digestible energy components used in the enteric fermentation inventory can be used to cross-check independently-derived VS rates. Application of Equation 10.24 (Volatile solid excretion rates) can be used in this case for such a cross-comparison on ruminants. For all animals, on a gross basis, VS rates should be consistent with the feed intake of the animal (i.e., waste energy should not exceed intake energy) and be consistent with the range of DE% values reported in Section 10.2, Table 10.2 of this report.
- Whenever possible, available measurement data, even if they represent only a small sample of systems, should be reviewed relative to assumptions for MCF values and CH_4 production estimates. Representative measurement data may provide insights into how well current assumptions predict CH_4 production from manure management systems in the inventory area, and how certain factors (e.g., temperature, system configuration, retention time) are affecting emissions. Because of the relatively small amount of measurement data available for these systems worldwide, any new results can improve the understanding of these emissions and possibly their prediction.

EXTERNAL REVIEW

- The inventory agency should utilise experts in manure management and animal nutrition to conduct expert peer review of the methods and data used. While these experts may not be familiar with greenhouse gas emissions, their knowledge of key input parameters to the emission calculation can aid in the overall verification of the emissions. For example, animal nutritionists can evaluate VS production rates to see if they are consistent with feed utilization research for certain livestock species. Practicing farmers can provide insights into actual manure management techniques, such as storage times and mixed-system usage. Wherever possible, these experts should be completely independent of the inventory process in order to allow a true external review.

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Volume 1, Chapter 6 (Quality assurance/Quality control and Verification). When country-specific data (e.g., emission factors, manure management practices, and manure characteristics such as VS and B_o) have been used, the derivation of or references for these data should be clearly documented and reported along with the inventory results under the appropriate IPCC source category. To improve transparency, emission estimates from this source category should be reported along with the activity data and emission factors used to determine the estimates.

The following information should be documented:

- All activity data (e.g., livestock population data by species/category and by region), including sources used, complete citations for the statistical database from which data were collected, and (in cases where activity data were not available directly from databases) the information and assumptions that were used to derive the activity data.

- Climatic conditions (e.g., average temperature during manure storage) in regions if applicable.
- Manure management system data, by livestock species/category and by region, if applicable. If manure management systems different than those defined in this chapter are used, these should be described.
- The frequency of data collection, and estimates of accuracy and precision.
- Emission factors documentation, including:
  - (i) References for the emission factors that were used (IPCC default or otherwise); and
  - (ii) The scientific basis of these emission factors and methods, including definition of input parameters and description of the process by which these emission factors and methods are derived, as well as describing sources and magnitudes of uncertainties. (In inventories, in which country- or region-specific emission factors were used or in which new methods other than those described here were used).
- If the Tier 1 method is used, all default emission factors used in the emissions estimation for the specific livestock population species/category.
- If the Tier 2 method is used, documentation of emission factor calculation components, including:
  - (i) VS and B_o values for all livestock population species/category in inventory, whether country-specific, region-specific, or IPCC default; and
  - (ii) MCF values for all manure management systems used, whether country-specific or IPCC default.

10.5 N_2O EMISSIONS FROM MANURE MANAGEMENT

The section describes how to estimate the N_2O produced, directly and indirectly, during the storage and treatment of manure before it is applied to land or otherwise used for feed, fuel, or construction purposes. The term 'manure' is used here collectively to include both dung and urine (i.e., the solids and the liquids) produced by livestock. The N_2O emissions generated by manure in the system 'pasture, range, and paddock' occur directly and indirectly from the soil, and are therefore reported under the category '*N_2O Emissions from Managed Soils*' (see Chapter 11, Section 11.2). The emissions associated with the burning of dung for fuel are to be reported under 'Fuel Combustion' (see Volume 2: Energy), or under 'Waste Combustion' (see Volume 5: Waste) if burned without energy recovery.

Direct N_2O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, and on the duration of the storage and type of treatment. Nitrification (the oxidation of ammonia nitrogen to nitrate nitrogen) is a necessary prerequisite for the emission of N_2O from stored animal manures. Nitrification is likely to occur in stored animal manures provided there is a sufficient supply of oxygen. Nitrification does not occur under anaerobic conditions. Nitrites and nitrates are transformed to N_2O and dinitrogen (N_2) during the naturally occurring process of denitrification, an anaerobic process. There is general agreement in the scientific literature that the ratio of N_2O to N_2 increases with increasing acidity, nitrate concentration, and reduced moisture. In summary, the production and emission of N_2O from managed manures requires the presence of either nitrites or nitrates in an anaerobic environment preceded by aerobic conditions necessary for the formation of these oxidized forms of nitrogen. In addition, conditions preventing reduction of N_2O to N_2, such as a low pH or limited moisture, must be present.

Indirect emissions result from volatile nitrogen losses that occur primarily in the forms of ammonia and NO_x. The fraction of excreted organic nitrogen that is mineralized to ammonia nitrogen during manure collection and storage depends primarily on time, and to a lesser degree temperature. Simple forms of organic nitrogen such as urea (mammals) and uric acid (poultry) are rapidly mineralized to ammonia nitrogen, which is highly volatile and easily diffused into the surrounding air (Asman *et al.*, 1998; Monteny and Erisman, 1998). Nitrogen losses begin at the point of excretion in houses and other animal production areas (e.g., milk parlors) and continue through on-site management in storage and treatment systems (i.e., manure management systems). Nitrogen is also lost through runoff and leaching into soils from the solid storage of manure at outdoor areas, in feedlots and where animals are grazing in pastures. Pasture losses are considered separately in Chapter 11, Section 11.2, *N_2O Emissions from Managed Soils*, as are emissions of nitrogen compounds from grazing livestock.

Due to significant direct and indirect losses of manure nitrogen in management systems it is important to estimate the remaining amount of animal manure nitrogen available for application to soils or for use in feed, fuel, or construction purposes. This value is used for calculation N_2O emissions from managed soils (see Chapter 11, Section 11.2). The methodology to estimate manure nitrogen that is directly applied to soils, or available for use in feed, fuel, or construction purposes is described in this chapter under Section 10.5.4 “Coordination with reporting for N_2O emissions from managed soils".

10.5.1 Choice of method

The level of detail and methods chosen for estimating N_2O emissions from manure management systems will depend upon national circumstances and the decision tree in Figure 10.4 describes *good practice* in choosing a method accordingly. The following sections describe the different tiers referenced in the decision tree for calculating direct and indirect N_2O emissions from manure management systems.

Direct N_2O emissions from Manure Management

Tier 1

The Tier 1 method entails multiplying the total amount of N excretion (from all livestock species/categories) in each type of manure management system by an emission factor for that type of manure management system (see Equation 10.25). Emissions are then summed over all manure management systems. The Tier 1 method is applied using IPCC default N_2O emission factors, default nitrogen excretion data, and default manure management system data (see Annex 10A.2, Tables 10A-4 to 10A-8 for default management system allocations).

Tier 2

A Tier 2 method follows the same calculation equation as Tier 1 but would include the use of country-specific data for some or all of these variables. For example, the use of country-specific nitrogen excretion rates for livestock categories would constitute a Tier 2 methodology.

Tier 3

A Tier 3 method utilizes alternative estimation procedures based on a country-specific methodology. For example, a process-based, mass balance approach which tracks nitrogen throughout the system starting with feed input through final use/disposal could be utilized as a Tier 3 procedure. Tier 3 methods should be well documented to clearly describe estimation procedures.

To estimate emissions from manure management systems, the livestock population must first be divided into categories that reflect the varying amounts of manure produced per animal as well as the manner in which the manure is handled. This division of manure by type of system should be the same as that used to characterize methane emissions from manure management (see Section 10.4). For example, if Tier 1 default emission factors are used for calculating CH_4 emissions, then the manure management systems usage data from Tables 10A-4 to 10A-8 should be applied. Detailed information on how to characterise the livestock population for this source is provided in Section 10.2.

The following five steps are used to estimate direct N_2O emissions from Manure Management:

Step 1: Collect population data from the Livestock Population Characterisation;

Step 2: Use default values or develop the annual average nitrogen excretion rate per head ($Nex_{(T)}$) for each defined livestock species/category T;

Step 3: Use default values or determine the fraction of total annual nitrogen excretion for each livestock species/category T that is managed in each manure management system S ($MS_{(T,S)}$);

Step 4: Use default values or develop N_2O emission factors for each manure management system S ($EF_{3(S)}$); and

Step 5: For each manure management system type S, multiply its emission factor ($EF_{3(S)}$) by the total amount of nitrogen managed (from all livestock species/categories) in that system, to estimate N_2O emissions from that manure management system. Then sum over all manure management systems.

In some cases, manure nitrogen may be managed in several types of manure management systems. For example, manure flushed from a dairy freestall barn to an anaerobic lagoon may first pass through a solids separation unit where some of the manure nitrogen is removed and managed as a solid. Therefore, it is important to consider carefully the fraction of manure nitrogen that is managed in each type of system.

The calculation of direct N_2O emissions from manure management is based on the following equation:

EQUATION 10.25
DIRECT N2O EMISSIONS FROM MANURE MANAGEMENT

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)}\right)\right] \bullet EF_{3(S)}\right] \bullet \frac{44}{28}$$

Where:

$N_2O_{D(mm)}$ = direct N_2O emissions from Manure Management in the country, kg N_2O yr^{-1}

$N_{(T)}$ = number of head of livestock species/category *T* in the country

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* in the country, kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$EF_{3(S)}$ = emission factor for direct N_2O emissions from manure management system *S* in the country, kg N_2O-N/kg N in manure management system *S*

S = manure management system

T = species/category of livestock

44/28 = conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

There may be losses of nitrogen in other forms (e.g., ammonia and NO_x) as manure is managed on site. Nitrogen in the volatilized form of ammonia may be deposited at sites downwind from manure handling areas and contribute to indirect N_2O emissions (see below). Countries are encouraged to consider using a mass balance approach (Tier 3) to track the manure nitrogen excreted, managed on site in manure management systems, and ultimately applied to managed soils. The estimation of the amount of manure nitrogen which is directly applied to managed soils or otherwise available for use as feed, fuel or construction purposes is described in the Section 10.5.4, Coordination with reporting for N_2O emissions from managed soils. See Chapter 11, Section 11.2 for procedures to calculate N_2O emissions from managed manure nitrogen applied to soils.

Indirect N_2O emissions from Manure Management

Tier 1

The Tier 1 calculation of N volatilisation in forms of NH_3 and NO_x from manure management systems is based on multiplication of the amount of nitrogen excreted (from all livestock categories) and managed in each manure management system by a fraction of volatilised nitrogen (see Equation 10.26). N losses are then summed over all manure management systems. The Tier 1 method is applied using default nitrogen excretion data, default manure management system data (see Annex 10A.2, Tables 10A-4 to 10A-8) and default fractions of N losses from manure management systems due to volatilisation (see Table 10.22):

EQUATION 10.26
N LOSSES DUE TO VOLATILISATION FROM MANURE MANAGEMENT

$$N_{volatilization-MMS} = \sum_S \left[\sum_T \left[\left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)}\right) \bullet \left(\frac{Frac_{GasMS}}{100}\right)_{(T,S)}\right]\right]$$

Where:

$N_{volatilization-MMS}$ = amount of manure nitrogen that is lost due to volatilisation of NH_3 and NO_x, kg N yr^{-1}

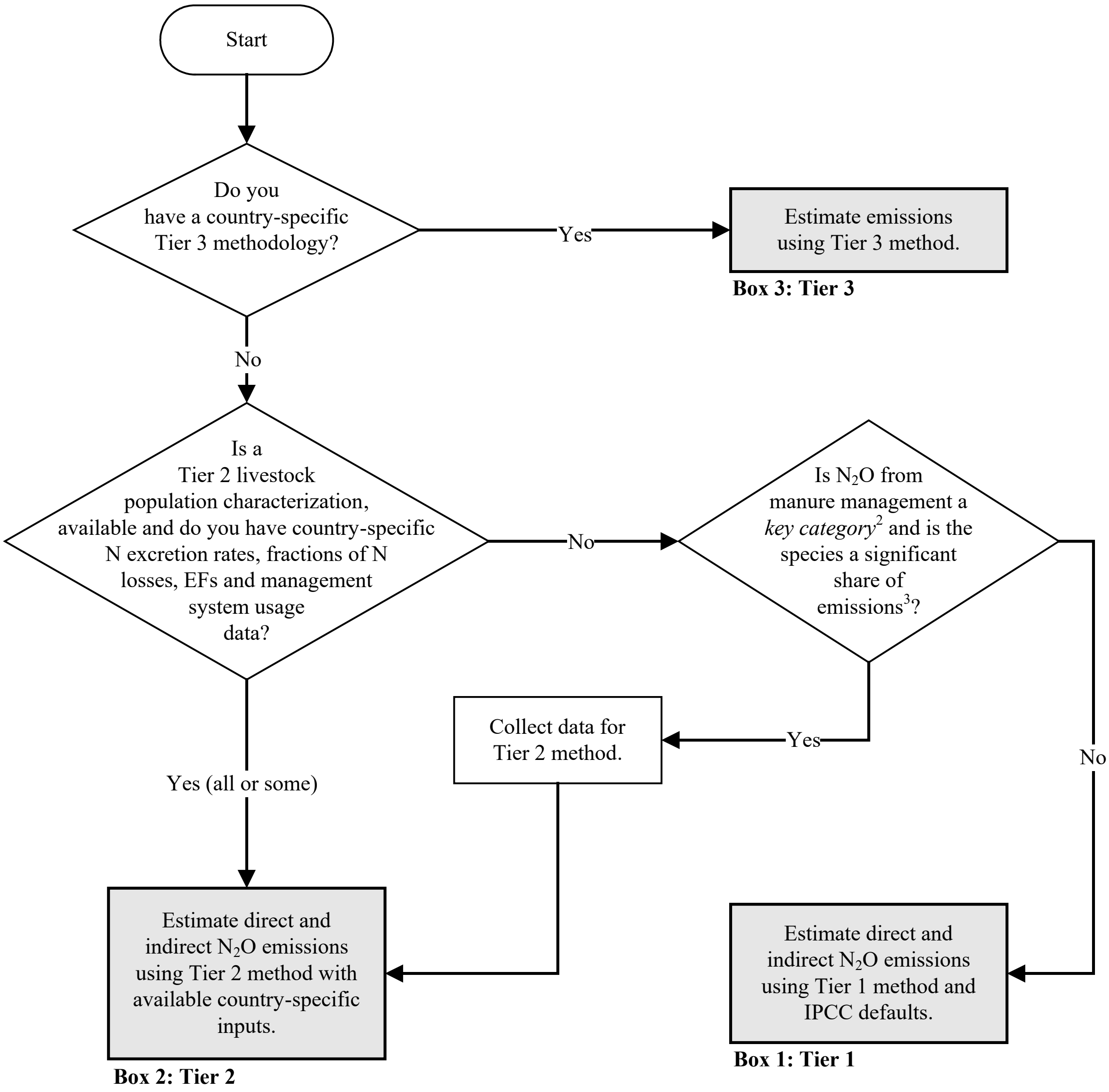
$N_{(T)}$ = number of head of livestock species/category *T* in the country

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* in the country, kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$Frac_{GasMS}$ = percent of managed manure nitrogen for livestock category *T* that volatilises as NH_3 and NO_x in the manure management system *S*, %

Figure 10.4 Decision tree for N_2O emissions from Manure Management (Note 1)



Note:
1: N_2O emissions from manure management systems include both direct and indirect sources
2: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting Section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.
3: As a rule of thumb, a livestock species would be significant if it accounts for 25-30% or more of emissions from the source category.

The indirect N_2O emissions from volatilisation of N in forms of NH_3 and NO_x ($N_2O_{G(mm)}$) are estimated using Equation 10.27:

EQUATION 10.27
INDIRECT N2O EMISSIONS DUE TO VOLATILISATION OF N FROM MANURE MANAGEMENT

$$N_2O_{G(mm)} = \left(N_{volatilization-MMS} \bullet EF_4\right) \bullet \frac{44}{28}$$

Where:

$N_2O_{G(mm)}$ = indirect N_2O emissions due to volatilization of N from Manure Management in the country, kg N_2O yr^{-1}

EF_4 = emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilised)$^{-1}$; default value is 0.01 kg N_2O-N (kg NH_3-N + NO_x-N volatilised)$^{-1}$, given in Chapter 11, Table 11.3

Tier 2

Countries may wish to develop a Tier 2 methodology for better consideration of national circumstances and to reduce uncertainty of estimates as much as possible. As for direct N_2O emission from manure management, a Tier 2 method would follow the same calculation equation as Tier 1 but include the use of country-specific data for some or all of these variables. For example, the use of country-specific nitrogen excretion rates for livestock categories would constitute a Tier 2 method. National NH_3 emission inventories developed by some countries could be used for Tier 2 estimation of nitrogen volatilisation from manure management systems. A Tier 2 method would require more detailed characterisation of the flow of nitrogen throughout the animal housing and manure management systems used in the country. Double counting of emissions associated with the application of managed manure should be avoided, as well as manure associated with pasture and grazing operations, which should be calculated and reported under Chapter 11, Section 11.2 (N_2O emissions from managed soils).

There are extremely limited measurement data on leaching and runoff losses from various manure management systems. The greatest N losses due to runoff and leaching typically occur where animals are on a drylot. In drier climates, runoff losses are smaller than in high rainfall areas and have been estimated in the range from 3 to 6% of N excreted (Eghball and Power, 1994). Studies by Bierman *et al.* (1999) found nitrogen lost in runoff was 5 to 19% of N excreted and 10 to 16% leached into soil, while other data show relatively low loss of nitrogen through leaching in solid storage (less than 5% of N excreted) but greater loss could also occur (Rotz, 2004). Further research is needed in this area to improve the estimated losses and the conditions and practices under which such losses occur. Equation 10.28 should only be used where there is country-specific information on the fraction of nitrogen loss due to leaching and runoff from manure management systems available. Therefore, estimation of N losses from leaching and runoff from manure management should be considered part of a Tier 2 or Tier 3method.

Nitrogen that leaches into soil and/or runs off during solid storage of manure at outdoor areas or in feedlots is derived as follows:

EQUATION 10.28
N LOSSES DUE TO LEACHING FROM MANURE MANAGEMENT SYSTEMS

$$N_{leaching-MMS} = \sum_S \left[\sum_T \left[\left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)}\right) \bullet \left(\frac{Frac_{leachMS}}{100}\right)_{(T,S)} \right] \right]$$

Where:

$N_{leaching-MMS}$ = amount of manure nitrogen that leached from manure management systems, kg N yr^{-1}

$N_{(T)}$ = number of head of livestock species/category *T* in the country

$Nex_{(T)}$ = annual average N excretion per head of species/category *T* in the country, kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$Frac_{leachMS}$ = percent of managed manure nitrogen losses for livestock category *T* due to runoff and leaching during solid and liquid storage of manure

The indirect N_2O emissions from leaching and runoff of nitrogen from manure management systems ($N_2O_{L(mm)}$) are estimated using Equation 10.29:

EQUATION 10.29
INDIRECT N_2O EMISSIONS DUE TO LEACHING FROM MANURE MANAGEMENT

$$N_2O_{L(mm)} = \left(N_{leaching-MMS} \bullet EF_5\right) \bullet \frac{44}{28}$$

Where:

$N_2O_{L(mm)}$ = indirect N_2O emissions due to leaching and runoff from Manure Management in the country, kg N_2O yr^{-1}

EF_5 = emission factor for N_2O emissions from nitrogen leaching and runoff, kg N_2O-N/kg N leached and runoff (default value 0.0075 kg N_2O-N (kg N leaching/runoff)$^{-1}$, given in Chapter 11, Table 11.3

Tier 3

To reduce uncertainty of the estimates, a Tier 3 method could be developed with country-specific emission factors for volatilisation and nitrogen leaching and runoff based on actual measurements.

All losses of N through manure management systems (both direct and indirect) need to be excluded from the amount of manure N that is available for application to soils and which is reported in Chapter 11, Section 11.2 *N_2O Emissions from Managed Soils*. Refer to Section 10.5.4, Coordination with reporting for N_2O emissions from managed soils, for guidance on calculating total N losses from manure management systems.

10.5.2 Choice of emission factors

Annual average nitrogen excretion rates, $Nex_{(T)}$

Tier 1

Annual nitrogen excretion rates should be determined for each livestock category defined by the livestock population characterisation. Country-specific rates may either be taken directly from documents or reports such as agricultural industry and scientific literature, or derived from information on animal nitrogen intake and retention (as explained below). In some situations, it may be appropriate to use excretion rates developed by other countries that have livestock with similar characteristics.

If country-specific data cannot be collected or derived, or appropriate data are not available from another country, the IPCC default nitrogen excretion rates presented in Table 10.19 can be used. These rates are presented in units of nitrogen excreted per 1000 kg of animal per day. These rates can be applied to livestock sub-categories of varying ages and growth stages using a typical average animal mass (TAM) for that population sub-category, as shown in Equation 10.30.

EQUATION 10.30
ANNUAL N EXCRETION RATES

$$Nex_{(T)} = N_{rate(T)} \bullet \frac{TAM}{1000} \bullet 365$$

Where:

$Nex_{(T)}$ = annual N excretion for livestock category *T*, kg N animal^{-1} yr^{-1}

$N_{rate(T)}$ = default N excretion rate, kg N (1000 kg animal mass)$^{-1}$ day^{-1} (see Table 10.19)

$TAM_{(T)}$ = typical animal mass for livestock category *T*, kg animal^{-1}

Default TAM values are provided in Tables 10A-4 to 10A-9 in Annex 10A.2. However, it is preferable to collect country-specific TAM values due to the sensitivity of nitrogen excretion rates to different weight categories. For example, market swine may vary from nursery pigs weighing less than 30 kilograms to finished pigs that weigh over 90 kilograms. By constructing animal population groups that reflect the various growth stages of market pigs, countries will be better able to estimate the total nitrogen excreted by their swine population.

When estimating the $Nex_{(T)}$ for animals whose manure is classified in the manure management system *burned for fuel* (Table 10.21, Default emission factors for direct N_2O emissions from Manure Management), it should be kept in mind that the dung is burned and the urine stays in the field. As a rule of thumb, 50% of the nitrogen excreted is in the dung and 50% is in the urine. If the burned dung is used as fuel, then emissions are reported under the IPCC category *Fuel Combustion* (Volume 2: Energy), whereas if the dung is burned without energy recovery the emissions should be reported under the IPCC category *Waste Incineration* (Volume 5: Waste).

Tier 2

The annual amount of N excreted by each livestock species/category depends on the total annual N intake and total annual N retention of the animal. Therefore, N excretion rates can be derived from N intake and N retention data. Annual N intake (i.e., the amount of N consumed by the animal annually) depends on the annual amount of feed digested by the animal, and the protein content of that feed. Total feed intake depends on the production level of the animal (e.g., growth rate, milk production, draft power). Annual N retention (i.e., the fraction of N intake that is retained by the animal for the production of meat, milk, or wool) is a measure of the animal's efficiency of production of animal protein from feed protein. Nitrogen intake and retention data for specific livestock species/categories may be available from national statistics or from animal nutrition specialists. Nitrogen intake can also be calculated from data on feed and crude protein intake developed in Section 10.2. Default N retention values are provided in Table 10.20, Default values for the fraction of nitrogen in feed taken in by animals that is retained by the different animal species/categories. Rates of annual N excretion for each livestock species/category ($Nex_{(T)}$) are derived as follows:

EQUATION 10.31
ANNUAL N EXCRETION RATES (TIER 2)

$$Nex_{(T)} = N_{intake(T)} \bullet (1 - N_{retention\_frac(T)}) \bullet 365$$

Where:

$Nex_{(T)}$ = annual N excretion rates, kg N animal^{-1} yr^{-1}

$N_{intake(T)}$ = the daily N intake per head of animal of species/category T, kg N animal^{-1} day^{-1}

$N_{retention\_frac(T)}$ = fraction of N intake that is retained by animal of species/category T, dimensionless

Example of Tier 2 method for estimating nitrogen excretion for cattle

Nitrogen excretion may be calculated based on the same dietary assumptions used in modelling enteric fermentation emissions (see Section 10.2). The amount of nitrogen excreted by cattle can be estimated as the difference between the total nitrogen taken in by the animal and the total nitrogen retained for growth and milk production. Equations 10.32 and 10.33 can be used to calculate the variables for nitrogen intake and nitrogen retained for use in Equation 10.31. The total nitrogen intake rate is derived as follows:

EQUATION 10.32
N INTAKE RATES FOR CATTLE

$$N_{intake(T)} = \frac{GE}{18.45} \bullet \left(\frac{\frac{CP\%}{100}}{6.25} \right)$$

Where:

$N_{intake(T)}$ = daily N consumed per animal of category T, kg N animal^{-1} day^{-1}

GE = gross energy intake of the animal, in enteric model, based on digestible energy, milk production, pregnancy, current weight, mature weight, rate of weight gain, and IPCC constants, MJ animal^{-1} day^{-1}

18.45 = conversion factor for dietary GE per kg of dry matter, MJ kg^{-1}. This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

CP% = percent crude protein in diet, input

6.25 = conversion from kg of dietary protein to kg of dietary N, kg feed protein (kg N)$^{-1}$

TABLE 10.19
DEFAULT VALUES FOR NITROGEN EXCRETION RATE [a] (KG N (1000 KG ANIMAL MASS)$^{-1}$ DAY^{-1})

Category of animal	**Region**							
	North America	**Western Europe**	**Eastern Europe**	**Oceania**	**Latin America**	**Africa**	**Middle East**	**Asia**
Dairy Cattle	0.44	0.48	0.35	0.44	0.48	0.60	0.70	0.47
Other Cattle	0.31	0.33	0.35	0.50	0.36	0.63	0.79	0.34
Swine[b]	0.40	0.50	0.54	0.52	1.47	1.47	1.47	0.40
Market	0.42	0.51	0.55	0.53	1.57	1.57	1.57	0.42
Breeding	0.24	0.42	0.46	0.46	0.55	0.55	0.55	0.24
Poultry	0.83	0.83	0.82	0.82	0.82	0.82	0.82	0.82
Hens >/= 1 yr	0.83	0.96	0.82	0.82	0.82	0.82	0.82	0.82
Pullets	0.62	0.55	0.60	0.60	0.60	0.60	0.60	0.60
Other Chickens	0.83	0.83	0.82	0.82	0.82	0.82	0.82	0.82
Broilers	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Turkeys	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
Ducks	0.83	0.83	0.83	0.83	0.83	0.83	0.83	0.83
Sheep	0.42	0.85	0.90	1.13	1.17	1.17	1.17	1.17
Goats	0.45	1.28	1.28	1.42	1.37	1.37	1.37	1.37
Horses (and mules, asses)	0.30	0.26	0.30	0.30	0.46	0.46	0.46	0.46
Camels[c]	0.38	0.38	0.38	0.38	0.46	0.46	0.46	0.46
Buffalo[c]	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
Mink and Polecat (kg N head^{-1} yr^{-1})[d]	4.59	4.59	4.59	4.59	4.59	4.59	4.59	4.59
Rabbits (kg N head^{-1} yr^{-1})	8.10	8.10	8.10	8.10	8.10	8.10	8.10	8.10
Fox and Racoon (kg N head^{-1} yr^{-1})[d]	12.09	12.09	12.09	12.09	12.09	12.09	12.09	12.09

The uncertainty in these estimates is ±50%.

[a] Summarized from *1996 IPCC Guidelines*, 1997; European Environmental Agency, 2002; USA EPA National NH_3 Inventory Draft Report, 2004; and data of GHG inventories of Annex I Parties submitted to the Secretariat UNFCCC in 2004.

[b] Nitrogen excretion for swine are based on an estimated country population of 90% market swine and 10% breeding swine.

[c] Modified from European Environmental Agency, 2002.

[d] Data of Hutchings *et al.*, 2001.

TABLE 10.20
DEFAULT VALUES FOR THE FRACTION OF NITROGEN IN FEED INTAKE OF LIVESTOCK THAT IS RETAINED BY THE DIFFERENT LIVESTOCK SPECIES/CATEGORIES (FRACTION N-INTAKE RETAINED BY THE ANIMAL)

Livestock category	$N_{retention\_frac(T)}$ (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$
Dairy Cows	0.20
Other Cattle	0.07
Buffalo	0.07
Sheep	0.10
Goats	0.10
Camels	0.07
Swine	0.30
Horses	0.07
Poultry	0.30

The uncertainty in these estimates is ±50%.
Source: Judgement of IPCC Expert Group (see Co-chairs, Editors and Experts; N_2O emissions from Manure Management).

The total nitrogen retained is derived as follows:

EQUATION 10.33
N RETAINED RATES FOR CATTLE

$$N_{retention(T)} = \left[\frac{Milk \bullet \left(\frac{Milk\ PR\%}{100} \right)}{6.38} \right] + \left[\frac{WG \bullet \left[268 - \left(\frac{7.03 \bullet NE_g}{WG} \right) \right]}{1000 \bullet 6.25} \right]$$

Where:

$N_{retention(T)}$ = daily N retained per animal of category T, kg N animal^{-1} day^{-1}

Milk = milk production, kg animal^{-1} day^{-1} (applicable to dairy cows only)

Milk PR% = percent of protein in milk, calculated as [1.9 + 0.4 ● %Fat], where %Fat is an input, assumed to be 4% (applicable to dairy cows only)

6.38 = conversion from milk protein to milk N, kg Protein (kg N)$^{-1}$

WG = weight gain, input for each livestock category, kg day^{-1}

268 = constant derived from Equation 3-8 in NRC (1996), g Protein kg^{-1} animal^{-1}

7.03 = constant derived from Equation 3-8 in NRC (1996), g Protein MJ^{-1} animal^{-1}

NEg = net energy for growth, calculated in livestock characterisation, based on current weight, mature weight, rate of weight gain, and IPCC constants, MJ day^{-1}

6.25 = conversion from kg dietary protein to kg dietary N, kg Protein (kg N)$^{-1}$

Annual nitrogen excretion data are also used for the calculation of direct and indirect N_2O emissions from managed soils (see Chapter 11, Section 11.2, N_2O emissions from managed soils). The same rates of N excretion, and methods of derivation, that are used to estimate N_2O emissions from Manure Management should be used to estimate N_2O emissions from managed soils.

Emission factors for direct N_2O emissions from Manure Management

The best estimate will be obtained using country-specific emission factors that have been fully documented in peer reviewed publications. It is *good practice* to use country-specific emission factors that reflect the actual duration of storage and type of treatment of animal manure in each management system that is used. *Good* *practice* in the derivation of country-specific emission factors involves the measurement of emissions (per unit of manure N) from different management systems, taking into account variability in duration of storage and types of treatment. When defining types of treatment, conditions such as aeration and temperature should be taken into account. If inventory agencies use country-specific emission factors, they are encouraged to provide justification for these values via peer-reviewed documentation.

If appropriate country-specific emission factors are unavailable, inventory agencies are encouraged to use the default emission factors presented in Table 10.21, Default emission factors for direct N_2O emissions from Manure Management. This table contains default emission factors by manure management system. Note that emissions from liquid/slurry systems without a natural crust cover, anaerobic lagoons, and anaerobic digesters are considered negligible based on the absence of oxidized forms of nitrogen entering these systems combined with the low potential for nitrification and denitrification to occur in the system.

Emission factors for indirect N_2O emissions from Manure Management

In order to estimate indirect N_2O emissions from Manure Management, two fractions of nitrogen losses (due to volatilization and leaching/runoff), and two indirect N_2O emissions factors associated with these losses (EF_4 and EF_5) are needed. Default values for volatilization N losses are presented in the Table 10.22. Values represent average rates for N loss in the forms of NH_3 and NO_x, with most of the loss in the form of NH_3. Ranges reflect values that appear in the literature. The values represent conditions without any significant nitrogen control measures in place. Countries are encouraged to develop country-specific values, particularly related to ammonia losses where component emissions may be well characterized as part of larger air quality assessments and where emissions may be affected by nitrogen reduction strategies. For example, detailed methodologies for estimating NH_3 and other nitrogen losses using mass balance/mass flow procedures are described in the EMEP/CORINAIR Atmospheric Inventory Guidebook, Chapter 1009 (European Environmental Agency, 2002).

The fraction of manure nitrogen that leaches from manure management systems ($Frac_{leachMS}$) is highly uncertain and should be developed as a country-specific value applied in Tier 2 method.

Default values for EF_4 (N volatilisation and re-deposition) and EF_5 (N leaching/runoff) are given in Chapter 11, Table 11.3 (Default emission, volatilisation and leaching factors for indirect soil N_2O emissions).

10.5.3 Choice of activity data

There are two main types of activity data for estimating N_2O emissions from manure management systems: (1) livestock population data, and (2) manure management system usage data.

Livestock population data, $N_{(T)}$

The animal population data should be obtained using the approach described in Section 10.2. If using default nitrogen excretion rates to estimate N_2O emissions from manure management systems, a Tier 1 livestock population characterisation is sufficient. To estimate N_2O emissions from Manure Management using calculated nitrogen excretion rates, a Tier 2 characterisation must be performed. As noted in Section 10.2, *good practice* in characterising livestock populations is to conduct a single characterisation that will provide the activity data for all emissions sources that depend on livestock population data.

Manure management system usage data, $MS_{(T,S)}$

The manure management system usage data used to estimate N_2O emissions from Manure Management should be the same as those that are used to estimate CH_4 emissions from Manure Management (see Table 10.18 for a summary of the main types of manure management systems). The portion of manure managed in each manure management system must be collected for each representative livestock category. Note that in some cases, manure may be managed in several types of manure management systems. For example, manure flushed from a dairy freestall barn to an anaerobic lagoon may first pass through a solids separation unit where some of the manure solids are removed and managed as a solid. Therefore, it is important to carefully consider the fraction of manure that is managed in each type of system.

The best means of obtaining manure management system distribution data is to consult regularly published national statistics. If such statistics are unavailable, the preferred alternative is to conduct an independent survey of manure management system usage. If the resources are not available to conduct a survey, experts should be consulted to obtain an opinion of the system distribution. If country-specific manure management system usage data are not available, default values should be used. The IPCC default values for dairy cows, other cattle, buffalo, swine (market and breeding swine), and poultry should be taken from Tables 10A-4 through 10A-8 of Annex 10A.2. Manure from other animal categories is typically managed in pastures and grazing operations.

TABLE 10.21
DEFAULT EMISSION FACTORS FOR DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

System	Definition		EF_3 [kg N_2O-N (kg Nitrogen excreted)$^{-1}$]	Uncertainty ranges of EF_3	Source[a]
Pasture/Range/ Paddock	The manure from pasture and range grazing animals is allowed to lie as is, and is not managed.		Direct and indirect N_2O emissions associated with the manure deposited on agricultural soils and pasture, range, paddock systems are treated in Chapter 11, Section 11.2, N_2O emissions from managed soils.		
Daily spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion. N_2O emissions during storage and treatment are assumed to be zero. N_2O emissions from land application are covered under the Agricultural Soils category.		0	Not applicable	Judgement by IPCC Expert Group (see Co-chairs, Editors and Experts; N_2O emissions from Manure Management).
Solid storage[b]	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.		0.005	Factor of 2	Judgement of IPCC Expert Group in combination with Amon *et al.* (2001), which shows emissions ranging from 0.0027 to 0.01 kg N_2O-N (kg N)$^{-1}$.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically. Dry lots are most typically found in dry climates but also are used in humid climates.		0.02	Factor of 2	Judgement of IPCC Expert Group in combination with Kulling (2003).
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water to facilitate handling and is stored in either tanks or earthen ponds.	With natural crust cover	0.005	Factor of 2	Judgement of IPCC Expert Group in combination with Sommer *et al.* (2000).
		Without natural crust cover	0	Not applicable	Judgement of IPCC Expert Group in combination with the following studies: Harper *et al.* (2000), Lague *et al.* (2004), Monteny *et al.* (2001), and Wagner-Riddle and Marinier (2003). Emissions are believed negligible based on the absence of oxidized forms of nitrogen entering systems in combination with low potential for nitrification and denitrification in the system.
Uncovered anaerobic lagoon	Anaerobic lagoons are designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields.		0	Not applicable	Judgement of IPCC Expert Group in combination with the following studies: Harper *et al.* (2000), Lague *et al.* (2004), Monteny *et al.* (2001), and Wagner-Riddle and Marinier (2003). Emissions are believed negligible based on the absence of oxidized forms of nitrogen entering systems in combination with low potential for nitrification and denitrification in the system.
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility.		0.002	Factor of 2	Judgement of IPCC Expert Group in combination with the following studies: Amon *et al.* (2001), Kulling (2003), and Sneath *et al.* (1997).

TABLE 10.21 (CONTINUED)
DEFAULT EMISSION FACTORS FOR DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

<table>
<tr><th>System</th><th colspan="2">Definition</th><th>EF_3 [kg N_2O-N (kg Nitrogen excreted)$^{-1}$]</th><th>Uncertainty ranges of EF_3</th><th>Source[a]</th></tr>
<tr><td>Anaerobic digester</td><td colspan="2">Anaerobic digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CH_4 and CO_2, which is captured and flared or used as a fuel.</td><td>0</td><td>Not applicable</td><td>Judgement of IPCC Expert Group in combination with the following studies: Harper *et al.* (2000), Lague *et al.* (2004) Monteny *et al.* (2001), and Wagner-Riddle and Marinier (2003). Emissions are believed negligible based on the absence of oxidized forms of nitrogen entering systems in combination with low potential for nitrification and denitrification in the system.</td></tr>
<tr><td rowspan="2">Burned for fuel or as waste</td><td colspan="2">The dung is excreted on fields. The sun dried dung cakes are burned for fuel.</td><td colspan="3">The emissions associated with the burning of the dung are to be reported under the IPCC category 'Fuel Combustion' if the dung is used as fuel and under the IPCC category 'Waste Incineration' if the dung is burned without energy recovery.</td></tr>
<tr><td colspan="2">Urine N deposited on pasture and paddock</td><td colspan="3">Direct and indirect N_2O emissions associated with the urine deposited on agricultural soils and pasture, range, paddock systems are treated in Chapter 11, Section 11.2, N_2O emissions from managed soils.</td></tr>
<tr><td rowspan="2">Cattle and swine deep bedding</td><td rowspan="2">As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.</td><td>No mixing</td><td>0.01</td><td>Factor of 2</td><td>Average value based on Sommer and Moller (2000), Sommer (2000), Amon *et al.* (1998), and Nicks *et al.* (2003).</td></tr>
<tr><td>Active mixing</td><td>0.07</td><td>Factor of 2</td><td>Average value based on Nicks *et al.* (2003) and Moller *et al.* (2000). Some literature cites higher values to 20% for well maintained, active mixing, but those systems included treatment for ammonia which is not typical.</td></tr>
<tr><td>Composting - In-Vessel[c]</td><td colspan="2">Composting, typically in an enclosed channel, with forced aeration and continuous mixing.</td><td>0.006</td><td>Factor of 2</td><td>Judgement of IPCC Expert Group. Expected to be similar to static piles.</td></tr>
<tr><td>Composting - Static Pile[c]</td><td colspan="2">Composting in piles with forced aeration but no mixing.</td><td>0.006</td><td>Factor of 2</td><td>Hao *et al.* (2001).</td></tr>
<tr><td>Composting - Intensive Windrow[c]</td><td colspan="2">Composting in windrows with regular turning for mixing and aeration.</td><td>0.1</td><td>Factor of 2</td><td>Judgement of IPCC Expert Group. Expected to be greater than passive windrows and intensive composting operations, as emissions are a function of the turning frequency.</td></tr>
<tr><td>Composting - Passive Windrow[c]</td><td colspan="2">Composting in windrows with infrequent turning for mixing and aeration.</td><td>0.01</td><td>Factor of 2</td><td>Hao *et al.* (2001).</td></tr>
<tr><td>Poultry manure with litter</td><td colspan="2">Similar to deep bedding systems. Typically used for all poultry breeder flocks and for the production of meat type chickens (broilers) and other fowl.</td><td>0.001</td><td>Factor of 2</td><td>Judgement of IPCC Expert Group based on the high loss of ammonia from these systems, which limits the availability of nitrogen for nitrification/denitrification.</td></tr>
<tr><td>Poultry manure without litter</td><td colspan="2">May be similar to open pits in enclosed animal confinement facilities or may be designed and operated to dry the manure as it accumulates. The latter is known as a high-rise manure management system and is a form of passive windrow composting when designed and operated properly.</td><td>0.001</td><td>Factor of 2</td><td>Judgement of IPCC Expert Group based on the high loss of ammonia from these systems, which limits the availability of nitrogen for nitrification/denitrification.</td></tr>
</table>

TABLE 10.21 (CONTINUED)
DEFAULT EMISSION FACTORS FOR DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

System	Definition		EF_3 [kg N_2O-N (kg Nitrogen excreted)$^{-1}$]	Uncertainty ranges of EF_3	Source[a]
Aerobic treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration. Natural aeration is limited to aerobic and facultative ponds and wetland systems and is due primarily to photosynthesis. Hence, these systems typically become anoxic during periods without sunlight.	Natural aeration systems	0.01	Factor of 2	Judgement of IPCC Expert Group. Nitrification-denitrification is used widely for the removal of nitrogen in the biological treatment of municipal and industrial wastewaters with negligible N_2O emissions. Limited oxidation may increase emissions compared to forced aeration systems.
		Forced aeration systems	0.005	Factor of 2	Judgement of IPCC Expert Group. Nitrification-denitrification is used widely for the removal of nitrogen in the biological treatment of municipal and industrial wastewaters with negligible N_2O emissions.

[a] Also see Dustan (2002), which compiled information from some of the original references cited.

[b] Quantitative data should be used to distinguish whether the system is judged to be a solid storage or liquid/slurry. The borderline between dry and liquid can be drawn at 20% dry matter content.

[c] Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

10.5.4 Coordination with reporting for N_2O emissions from managed soils

Following storage or treatment in any system of manure management, nearly all the manure will be applied to land. The emissions that subsequently arise from the application of the manure to soil are to be reported under the category *N_2O emissions from managed soils*. The methods for estimating these emissions are discussed in Chapter 11, Section 11.2. In estimating N_2O emissions from managed soils, the amount of animal manure nitrogen that is directly applied to soils, or available for use in feed, fuel, or construction purposes, are considered.

A significant proportion of the total nitrogen excreted by animals in managed systems (i.e., all livestock except those in pasture and grazing conditions) is lost prior to final application to managed soils or for use as feed, fuel, or for construction purposes. In order to estimate the amount of animal manure nitrogen that is directly applied to soils, or available for use in feed, fuel, or construction purposes (i.e., the value which is used in Chapter 11, Equation 11.1 or 11.2), it is necessary to reduce the total amount of nitrogen excreted by animals in managed systems by the losses of N through volatilisation (i.e., NH_3, N_2 and NO_x), conversion to N_2O and losses through leaching and runoff.

Where organic forms of bedding material (straw, sawdust, chippings, etc.) are used, the additional nitrogen from the bedding material should also be considered as part of the managed manure N applied to soils. Bedding is typically collected with the remaining manure and applied to soils. It should be noted, however, that since mineralization of nitrogen compounds in beddings occurs more slowly compared to manure and the concentration of ammonia fraction in organic beddings is negligible, both volatilization and leaching losses during storage of bedding are assumed to be zero (European Environmental Agency, 2002).

TABLE 10.22
DEFAULT VALUES FOR NITROGEN LOSS DUE TO VOLATILISATION OF NH_3 AND NO_X FROM MANURE MANAGEMENT

Animal type	**Manure management system (MMS)** [a]	**N loss from MMS due to volatilisation of N-NH_3 and N-NO_x (%)** [b] **$Frac_{GasMS}$ (Range of $Frac_{GasMS}$)**
Swine	Anaerobic lagoon	40% (25 – 75)
	Pit storage	25% (15 – 30)
	Deep bedding	40% (10 – 60)
	Liquid/slurry	48% (15 – 60)
	Solid storage	45% (10 – 65)
Dairy Cow	Anaerobic lagoon	35% (20 – 80)
	Liquid/Slurry	40% (15 – 45)
	Pit storage	28% (10 – 40)
	Dry lot	20% (10 – 35)
	Solid storage	30% (10 – 40)
	Daily spread	7% (5 – 60)
Poultry	Poultry without litter	55% (40 – 70)
	Anaerobic lagoon	40% (25 – 75)
	Poultry with litter	40% (10 – 60)
Other Cattle	Dry lot	30% (20 – 50)
	Solid storage	45% (10 – 65)
	Deep bedding	30% (20 – 40)
Other [c]	Deep bedding	25% (10 – 30)
	Solid storage	12% (5 – 20)

[a] Manure Management System here includes associated N losses at housing and final storage system.

[b] Volatilization rates based on judgement of IPCC Expert Group and following sources: Rotz (2003), Hutchings *et al.* (2001), and U.S EPA (2004).

[c] Other includes sheep, horses, and fur-bearing animals.

The estimate of managed manure nitrogen available for application to managed soils, or available for use in feed, fuel, or construction purposes is based on the following equation:

EQUATION 10.34
MANAGED MANURE N AVAILABLE FOR APPLICATION TO MANAGED SOILS, FEED, FUEL OR CONSTRUCTION USES

$$N_{MMS\_Avb} = \sum_{S} \left\{ \sum_{(T)} \left[\begin{array}{c} \left[\left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right) \bullet \left(1 - \frac{Frac_{LossMS}}{100} \right) \right] + \\ \left[N_{(T)} \bullet MS_{(T,S)} \bullet N_{beddingMS} \right] \end{array} \right] \right\}$$

Where:

N_{MMS_Avb} = amount of managed manure nitrogen available for application to managed soils or for feed, fuel, or construction purposes, kg N yr^{-1}

$N_{(T)}$ = number of head of livestock species/category T in the country

$Nex_{(T)}$ = annual average N excretion per animal of species/category T in the country, kg N $animal^{-1}$ yr^{-1}

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless

$Frac_{LossMS}$ = amount of managed manure nitrogen for livestock category *T* that is lost in the manure management system *S*, % (see Table 10.23)

$N_{beddingMS}$ = amount of nitrogen from bedding (to be applied for solid storage and deep bedding MMS if known organic bedding usage), kg N animal^{-1} yr^{-1}

S = manure management system

T = species/category of livestock

Bedding materials vary greatly and inventory compilers should develop values for $N_{beddingMS}$ based on the characteristics of bedding material used in their livestock industries. Limited data from scientific literature indicates the amount of nitrogen contained in organic bedding material applied for dairy cows and heifers is usually around 7 kg N animal^{-1} yr^{-1}, for other cattle is 4 kg N animal^{-1} yr^{-1}, for market and breeding swine is around 0.8 and 5.5 kg N animal^{-1} yr^{-1}, respectively. For deep bedding systems, the amount of N in litter is approximately double these amounts (Webb, 2001; Döhler *et al.*, 2002).

Table 10.23 presents default values for total nitrogen losses from manure management systems. These default values include losses that occur from the point of excretion, including animal housing losses, manure storage losses, and losses from leaching and runoff at the manure storage system where applicable. For example, values provided for dairy anaerobic lagoon systems include nitrogen losses that occur in the dairy barn and milking parlour prior to the collection and treatment of manure, as well as those that occur from the lagoon.

There is a high level of variability in the range of total nitrogen losses from managed manure systems. As shown in Table 10.23, the majority of these are due to volatilization losses, primarily ammonia losses that occur rapidly following the excretion of the manure. However, losses also occur in the form of NO_3, N_2O, and N_2 as well from leaching and runoff that occurs where manure is stored in piles. The values in Table 10.23 reflect average values for typical housing/storage combinations for each animal category. Countries are encouraged to develop country-specific values, particularly related to ammonia losses where component emissions may be well characterised for local practices as part of larger air quality assessments and where emissions may be affected by nitrogen reduction strategies.

Countries may wish to develop an alternative approach for better consideration of national circumstances and to reduce uncertainty of estimates as much as possible. This approach would entail more detailed characterisation of the flow of nitrogen through the components of the animal housing and manure management systems used in the country, accounting for any mitigation activity (e.g., the use of covers over slurry tanks), and consideration of local practices, such as type of bedding material used.

10.5.5 Uncertainty assessment

EMISSION FACTORS – NITROGEN EXCRETION RATES

Uncertainty ranges for the default N excretion rates are estimated at about ±50% (Source: Judgement by IPCC Expert Group). The uncertainty ranges for the default N retention values provided here are also ±50% (see Table 10.20). If inventory agencies derive N excretion rates using accurate in-country statistics on N intake and N retention, the uncertainties associated with the N excretion rates may be reduced substantially. The degree of uncertainty may be further reduced by using direct emission measurements of nitrogen losses from specific manure management systems.

EMISSION FACTORS – DIRECT N_2O EMISSIONS

There are large uncertainties associated with the default emission factors for this source category (–50% to +100%). Accurate and well-designed emission measurements from well characterised types of manure and manure management systems can help reduce these uncertainties. These measurements must account for temperature, moisture conditions, aeration, manure N content, metabolisable carbon, duration of storage, and other aspects of treatment.

TABLE 10.23
DEFAULT VALUES FOR TOTAL NITROGEN LOSS FROM MANURE MANAGEMENT

Animal category	**Manure management system** [a]	**Total N loss from MMS** [b] **$Frac_{LossMS}$ (Range of $Frac_{LossMS}$)**
Swine	Anaerobic lagoon	78% (55 – 99)
	Pit storage	25% (15 – 30)
	Deep bedding	50% (10 – 60)
	Liquid/Slurry	48% (15 – 60)
	Solid storage	50% (20 – 70)
Dairy Cow	Anaerobic lagoon	77% (55 – 99)
	Liquid/Slurry	40% (15 – 45)
	Pit storage	28% (10 – 40)
	Dry lot	30% (10 – 35)
	Solid storage	40% (10 – 65)
	Daily spread	22% (15 – 60)
Poultry	Poultry without litter	55% (40 – 70)
	Anaerobic lagoon	77% (50 – 99)
	Poultry with litter	50% (20 – 80)
Other Cattle	Dry lot	40% (20 – 50)
	Solid storage	50% (20 – 70)
	Deep bedding	40% (10 – 50)
Other [c]	Deep bedding	35% (15 – 40)
	Solid storage	15% (5 – 20)

[a] Manure Management System here includes associated N losses at housing and final storage system.

[b] Total N loss rates based on judgement of IPCC Expert Group and following sources: Rotz (2003), Hutchings *et al.* (2001), and U.S EPA (2004). Rates include losses in forms of NH_3, NO_x, N_2O, and N_2 as well from leaching and runoff from solid storage and dry lots. Values represent average rates for typical housing and storage components without any significant nitrogen control measures in place. Ranges reflect values that appear in the literature. Where measures to control nitrogen losses are in place, alternative rates should be developed to reflect those measures.

[c] Other includes sheep, horses, and fur-bearing animals.

EMISSION FACTORS – INDIRECT N_2O EMISSIONS

Uncertainty ranges for default N losses due to volatilisation of NH_3 and NO_x and total N losses from manure management systems are presented in the Tables 10.22 and 10.23, respectively. The uncertainty associated with default emission factor for nitrogen volatilisation and re-deposition (EF_4) is given in Table 11.3 of Chapter 11. The uncertainty range for the default emission factor for leaching and runoff (EF_5) is also provided in Table 11.3. Caution should be taken when developing country-specific emission factors for volatilisation and re-deposition of nitrogen, since direct measurements could include transboundary atmospheric transport.

ACTIVITY DATA – LIVESTOCK POPULATIONS

See Section 10.2 (Livestock Population and Feed Characterisation) for discussion on uncertainty of animal population and feed characterisation data.

ACTIVITY DATA – MANURE MANAGEMENT SYSTEM USAGE

The uncertainty of the manure management system usage data will depend on the characteristics of each country's livestock industry and how information on manure management is collected. For example, for countries that rely almost exclusively on one type of management system, such as dry lot, the uncertainty associated with management system usage data can be 10% or less. However, for countries where there is a wide variety of management systems used with locally different operating practices, the uncertainty in management system usage data can be much higher, in the range of 25% to 50%, depending on the availability of reliable and representative survey data that differentiates animal populations by system usage. Preferably, each country should estimate the uncertainty associated with their management system usage data by using the methods described in Volume 1, Chapter 3.

10.5.6 Completeness, Time series, Quality assurance/Quality control and Reporting

A complete inventory should estimate N_2O emissions from all systems of manure management for all livestock species/categories. Countries are encouraged to use manure management system definitions that are consistent with those presented in Table 10.18. Population data should be cross-checked between main reporting mechanisms (such as FAO and national agricultural statistics databases) to ensure that information used in the inventory is complete and consistent. Because of the widespread availability of the FAO database of livestock information, most countries should be able to prepare, at a minimum, Tier 1 estimates for the major livestock categories. For more information regarding the completeness of livestock characterisation, see Section 10.2.

Developing a consistent time series of emission estimates for this source category requires, at a minimum, the collection of an internally consistent time series of livestock population statistics. General guidance on the development of a consistent time series is addressed in Volume 1, Chapter 5 of this report. In most countries, the other two activity data sets required for this source category (i.e., N excretion rates and manure management system usage data), as well as the manure management emission factors, will be kept constant for the entire time series. However, in some cases, there may be reasons to modify these values over time. For example, farmers may alter livestock feeding practices which could affect nitrogen excretion rates. A particular system of manure management may change due to operational practices or new technologies such that a revised emission factor is warranted. These changes in practices may be due to the implementation of explicit greenhouse gas mitigation measures, or may be due to changing agricultural practices without regard to greenhouse gases. Regardless of the driver of change, the parameters and emission factors used to estimate emissions must reflect the change. The inventory text should thoroughly explain how the change in farm practices or implementation of mitigation measures has affected the time series of activity data or emission factors.

It is *good practice* to implement general quality control checks as outlined in Volume 1, Chapter 6, Quality Assurance/Quality Control and Verification, and expert review of the emission estimates. Additional quality control checks and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source. The general QA/QC related to data processing, handling, and reporting should be supplemented with procedures discussed below:

Activity data check

- The inventory agency should review livestock data collection methods, in particular checking that livestock subspecies data were collected and aggregated correctly with consideration for the duration of production cycles. The data should be cross-checked with previous years to ensure the data are reasonable and consistent with the expected trend. Inventory agencies should document data collection methods, identify potential areas of bias, and evaluate the representativeness of the data.
- Manure management system allocation should be reviewed on a regular basis to determine if changes in the livestock industry are being captured. Conversion from one type of management system to another, and technical modifications to system configuration and performance, should be captured in the system modelling for the affected livestock.
- National agricultural policy and regulations may have an effect on parameters that are used to calculate manure emissions, and should be reviewed regularly to determine what impact they may have. For example, guidelines to reduce manure runoff into water bodies may cause a change in management practices, and thus affect the N distribution for a particular livestock category. Consistency should be maintained between the inventory and ongoing changes in agricultural practices.
- If using country-specific data for $Nex_{(T)}$ and $MS_{(T,S)}$, the inventory agency should compare these values to the IPCC default values. Significant differences, data sources, and methods of data derivation, should be documented.
- The nitrogen excretion rates, whether default or country-specific values, should be consistent with feed intake data as determined through animal nutrition analyses.

Review of emission factors

- The inventory agency should evaluate how well the implied N_2O emission factors and nitrogen excretion rates compare with alternative national data sources and with data from other countries with similar livestock practices. Significant differences should be investigated.
- If using country-specific emission factors, the inventory agency should compare them to the default factors and note differences. The development of country-specific emission factors should be explained and documented, and the results peer-reviewed by independent experts.

- Whenever possible, available measurement data, even if they represent only a small sample of systems, should be reviewed relative to assumptions for N_2O emission estimates. Representative measurement data may provide insights into how well current assumptions predict N_2O production from manure management systems in the inventory area, and how certain factors (e.g., feed intake, system configuration, retention time) are affecting emissions. Because of the relatively small amount of measurement data available for these systems worldwide, any new results can improve the understanding of these emissions and possibly their prediction.

External review

- The inventory agency should utilise experts in manure management and animal nutrition to conduct expert peer review of the methods and data used. While these experts may not be familiar with greenhouse gas emissions, their knowledge of key input parameters to the emission calculation can aid in the overall verification of the emissions. For example, animal nutritionists can evaluate N production rates to see if they are consistent with feed utilization research for certain livestock species. Practicing farmers can provide insights into actual manure management techniques, such as storage times and mixed-system usage. Wherever possible, these experts should be completely independent of the inventory process in order to allow a true external review.

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Volume 1, Chapter 6, Quality Assurance/Quality Control and Verification. When country-specific emission factors, fractions of N losses, N excretion rates, or manure management system usage data have been used, the derivation of or references for these data should be clearly documented and reported along with the inventory results under the appropriate IPCC source category.

N_2O emissions from different types of manure management systems have to be reported according to categories in Table 10.18. N_2O emissions from all types of manure management systems are to be reported under Manure Management, with two exceptions:

- Emissions from the manure management system for *pasture, range, and paddock* are to be reported under the IPCC source category *N_2O emissions from managed soils* because this manure is deposited directly on soils by the livestock.
- Emission from the manure management system *burned for fuel*, are to be reported under the IPCC category *Fuel Combustion* if the dung is used as fuel and under the IPCC category *Waste Incineration* if the dung is burned without energy recovery. It should be noted, however, if the urine nitrogen is not collected for burning it must be reported under N_2O emissions from *pasture, range, and paddock* animals.

10.5.7 Use of worksheets

Use the worksheets for Livestock N_2O contained in Annex 1 (AFOLU Worksheets) to calculate and report inventory information for default methodologies described in Section 10.5 *N_2O emission from manure management.* The following is a summary of the step-by-step instructions to follow when completing the worksheets. Note that columns are referred to using the symbols of the variables that both appear in the equations, as well as in column headings of the worksheets.

Step 1: Calculation of N excretion from manure management systems (see worksheet for category *Manure Management: Direct N_2O emissions from Manure Management, Category code 3A2, Sheet 1 of 1*). Make extra copies of the worksheet and complete one for each manure management systems (MMS).

Step 1A: Collect population data from the Livestock Population Characterisation and enter corresponding values in column $N_{(T)}$;

Step 1B: Use default values for N_{rate} and TAM (Equation 10.30 and using data from Table 10.19 and Tables 10A-4 to 10A-9) or develop the annual average nitrogen excretion rate per head ($Nex_{(T)}$) for each defined livestock species/category *T* and enter these values in columns N_{rate} and TAM, or $Nex_{(T)}$, respectively;

Step 1C: Enter in column $MS_{(T,S)}$ default values (see Tables 10A-4 through 10A-8 of Annex 10A.2) or determine the fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in each manure management system S ($MS_{(T,S)}$);

Step 1D: Multiply the number of heads (column $N_{(T)}$) by the value of N excretion rate per head ($Nex_{(T)}$) for each livestock species/category *T* (column $Nex_{(T)}$) and by the fraction of manure nitrogen per MMS (column $MS_{(T,S)}$) in order to estimate total nitrogen excretion for each MMS in kilograms per year (column NE_{MMS}). Enter the results in column NE_{MMS} of this sheet, and in column NE_{MMS} of Sheet 1of 2 and Sheet 2 of 2 for worksheets under category *Indirect N_2O emissions from Manure Management, Category code 3C6.*

Step 2: Calculation of direct N_2O emissions from manure management systems (see worksheet for category *Manure Management: Direct N_2O emissions from Manure Management, Category code 3A2, Sheet 1 of 1).*

Step 2A: Use default values (see Table 10.21) or develop direct N_2O emission factors for each manure management system S ($EF_{3(S)}$) and enter corresponding emission factor in the column $EF_{3(S)}$;

Step 2B: For each manure management system type S, multiply its emission factor (column $EF_{3(S)}$) by the amount of nitrogen managed (column NE_{MMS}) in that system, to estimate direct N_2O emissions per MMS. Note that emissions estimates should be reported in kg of N_2O. Enter the results in the column $N_2O_{D(mm)}$ of this sheet.

Step 3: Calculation of indirect N_2O emissions from manure management systems (see worksheet for category *Indirect N_2O emissions from Manure Management, Category code 3C6, Sheet 1 of 2*). Make extra copies of the worksheet using one for each MMS).

Step 3A: Enter in column $Frac_{GasMS}$ default values (see Table 10.22) or determine country-specific fraction of managed livestock manure nitrogen that volatilises as NH_3 and NO_x for each defined livestock species/category *T* per each MMS ($Frac_{GasMS}$);

Step 3B: Multiply the fraction of manure nitrogen that volatilises as NH_3 and NO_x (column $Frac_{GasMS}$) by the total amount of nitrogen excreted in each MMS per livestock categories (column NE_{MMS}) to estimate amount of manure nitrogen that is lost due to volatilisation of NH_3 and NO_x ($N_{volatilizations\text{-}MMS}$);

Step 3C: Use default value (see Table 11.3, Chapter 11, Section 11.2 *N_2O emissions from managed soils*) or develop country-specific emission factor for indirect N_2O emission from atmospheric deposition of nitrogen on soils and water surfaces and enter the emission factor in the column EF_4;

Step 3D: Multiply the amount of manure nitrogen that is lost due to volatilisation of NH_3 and NO_x (column $N_{volatilizations\text{-}MMS}$) by the emission factor (column EF_4), to calculate annual indirect N_2O emissions per MMS. Note that emissions estimates should be reported in kg of N_2O. Enter the results in the column $N_2O_{G(mm)}$ of this sheet.

Step 4: Calculation of manure N that is available for application to soils or for use in feed, fuel or construction purposes from manure management systems (see worksheet for category *Indirect N_2O emissions from Manure Management, Category code 3C6, Sheet 2 of 2).* Make extra copies of the worksheet using one for each MMS*).*

Step 4A: Enter in column $Frac_{lossMS}$ default values (see Table 10.23) or develop country-specific fraction of total nitrogen loss from manure managed in each MMS for each livestock species/category *T* ($Frac_{lossMS}$);

Step 4B: If country-specific values for organic bedding usage are available for solid storage or deep bedding MMS, calculate the amount of N from bedding by multiplying the number of animals associated with these two systems by the N content in bedding per animal. Enter results obtained in the column $N_{beddingMS}$.

Step 4C: Calculate managed manure N available for application to managed soils, feed, fuel or construction using Equation 10.34 and enter obtained results in column N_{MMS_Avb}. Then sum over all manure management systems. This value is used for calculation of N_2O emissions from managed soils (see worksheets in Annex 1).

Annex 10A.1 Data underlying methane default emission factors for Enteric Fermentation

This annex presents the data used to develop the default emission factors for methane emissions from Enteric Fermentation. The Tier 2 method was implemented with these data to estimate the default emission factors for cattle and buffalo.

TABLE 10A.1
DATA FOR ESTIMATING TIER 1 ENTERIC FERMENTATION CH_4 EMISSION FACTORS FOR DAIRY COWS IN TABLE 10.11

Regions	Weight, kg	Weight gain, kg day^{-1}	Feeding Situation	Milk, kg day^{-1}	Work, hr day^{-1}	%Pregnant	Digestibility of feed (DE%)	CH_4 conversion factor (Y_m)
North America[a]	600	0	Stall fed	23.0	0	90%	75%	6.5%
Western Europe	600	0	Stall fed	16.4	0	90%	70%	6.5%
Eastern Europe[b]	550	0	Stall fed	7.0	0	80%	60%	6.5%
Oceania[c]	500	0	Pasture/Range	6.0	0	80%	60%	6.5%
Latin America[d]	400	0	Pasture/Range	2.2	0	80%	60%	6.5%
Asia[e]	350	0	Stall fed	4.5	0	80%	60%	6.5%
Africa & Middle East	275	0	Stall fed	1.3	0	67%	60%	6.5%
Indian Subcontinent[f]	275	0	Stall fed	2.5	0	50%	55%	6.5%

[a] Based on estimates for the United States.

[b] Based on estimates for the former USSR.

[c] Based on average estimate for region.

[d] Based on estimates for Brazil.

[e] Based on estimates for China.

[f] Based on estimates for India.

Source: Gibbs and Johnson (1993).

TABLE 10A.2
DATA FOR ESTIMATING TIER 1 ENTERIC FERMENTATION CH_4 EMISSION FACTORS FOR OTHER CATTLE IN TABLE 10.11

Subcategory	Weight, kg	Weight gain, kg day^{-1}	Feeding situation	Milk, kg day^{-1}	Work, hr day^{-1}	%Pregnant	Digestibility of feed (DE%)	CH_4 conversion factor (Y_m)	Day weighted population mix %	Emission factors, kg CH_4 head^{-1} yr^{-1}
North America[a]										
Mature females	500	0.0	Pasture/Range	3.3	0.0	80%	60%	6.5%	36%	76
Mature males	800	0.0	Pasture/Range	0.0	0.0	0%	60%	6.5%	2%	81
Calves on milk	100	0.9	Pasture/Range	0.0	0.0	0%	NA	0.0%	16%	0
Calves on forage	185	0.9	Pasture/Range	0.0	0.0	0%	65%	6.5%	8%	48
Growing heifers/steers	265	0.7	Pasture/Range	0.0	0.0	0%	65%	6.5%	17%	55
Replacement/growing	375	0.4	Pasture/Range	0.0	0.0	0%	60%	6.5%	11%	66
Feedlot cattle	415	1.3	Stall fed	0.0	0.0	0%	75%	3.0%	11%	33
Western Europe										
Mature males	600	0.0	Pasture/Range	0.0	0.0	0%	60%	6.5%	22%	66
Replacement/growing	400	0.4	Pasture/Range	0.0	0.0	0%	60%	6.5%	54%	73
Calves on milk	230	0.3	Pasture/Range	0.0	0.0	0%	65%	0.0%	15%	0
Calves on forage	230	0.3	Pasture/Range	0.0	0.0	0%	65%	6.5%	8%	35
Eastern Europe[b]										
Mature females	500	0.0	Pasture/Range	3.3	0.0	67%	60%	6.5%	30%	75
Mature males	600	0.0	Pasture/Range	0.0	0.0	0%	60%	6.5%	22%	66
Young	230	0.4	Pasture/Range	0.0	0.0	0%	60%	6.5%	48%	45
Oceania[c]										
Mature females	400	0.0	Pasture/Range	2.4	0.0	67%	55%	6.5 %	51%	71
Mature males	450	0.0	Pasture/Range	0.0	0.0	0%	55%	6.5%	11%	61
Young	200	0.3	Pasture/Range	0.0	0.0	0%	55%	6.5%	38%	46

[a] Based on estimates for the United States; . [b] Based on estimates for the former USSR; [c] Based on average estimate for region.

Table 10A.2 (continued)
Data for estimating Tier 1 enteric fermentation CH_4 emission factors for Other Cattle in Table 10.11

Subcategory	Weight, kg	Weight gain, kg day^{-1}	Feeding situation	Milk, kg day^{-1}	Work, hr day^{-1}	%Pregnant	Digestibility of feed (DE%)	CH_4 conversion factor (Y_m)	Day weighted population mix %	Emission factors, kg CH_4 head^{-1} yr^{-1}
Latin America[d]										
Mature females	400	0.0	Large areas	1.1	0.0	67%	60%	6.5%	37%	64
Mature males	450	0.0	Large areas	0.0	0.0	0%	60%	6.5%	6%	61
Young	230	0.3	Large areas	0.0	0.0	0%	60%	6.5%	58%	49
Asia[e]										
Mature females- Farming	325	0.0	Stall fed	1.1	0.55	33%	55%	6.5%	27%	50
Mature females- Grazing	300	0.0	Pasture/Range	1.1	0.00	50%	60%	6.5%	9%	46
Mature males-Farming	450	0.0	Stall fed	0.0	1.37	0%	55%	6.5%	24%	59
Mature males-Grazing	400	0.0	Pasture/Range	0.0	0.00	0%	60%	6.5%	8%	48
Young	200	0.2	Pasture/Range	0.0	0.00	0%	60%	6.5%	32%	36
Africa										
Mature females	200	0.0	Stall fed	0.3	0.55	33%	55%	6.5%	13%	32
Draft bullocks	275	0.0	Stall fed	0.0	1.37	0%	55%	6.5%	13%	41
Mature females- Grazing	200	0.0	Large areas	0.3	0.00	33%	55%	6.5%	6%	41
Bulls- Grazing	275	0.0	Large areas	0.0	0.00	0%	55%	6.5%	25%	49
Young	75	0.1	Pasture/Range	0.0	0.00	0%	60%	6.5%	44%	16
Indian Subcontinent[f]										
Mature females	125	0.0	Stall fed	0.6	0.00	33%	50%	6.5%	40%	28
Mature males	200	0.0	Stall fed	0.0	2.74	0%	50%	6.5%	10%	42
Young	80	0.1	Stall fed	0.0	0.00	0%	50%	6.5%	50%	23

[d] Based on estimates for the Brazil.; [e] Based on estimates for the China.; [f] Based on estimates for India; Source: Gibbs and Johnson (1993)

TABLE 10A.3
DATA FOR ESTIMATING TIER 1 ENTERIC FERMENTATION CH_4 EMISSION FACTORS FOR BUFFALO

Subcategory	Weight, kg	Weight gain, kg day^{-1}	Feeding situation	Milk, kg day^{-1}	Work, hr day^{-1}	%Preg-nant	Digestibility of feed (DE%)	CH_4 conversion factor (Y_m)	Day weighed population mix %	Emissions factors, kg CH_4 head^{-1} yr^{-1}
Indian Subcontinent[a]										
Adult males	350 - 550	0.00	Stall fed	0.00	1.37	0%	55%	6.5%	14%	55 - 77
Adult females	250 - 450	0.00	Stall fed	2.70	0.55	33%	55%	6.5%	40%	57 - 80
Young	100 - 300	0.15	Stall fed	0.00	0.00	0%	55%	6.5%	46%	23 - 50
Other Countries[b]										
Adult males	350 - 550	0.00	Stall fed	0.00	1.37	0%	55%	6.5%	45%	55 - 77
Adult females	250 - 450	0.00	Stall fed	0.65	0.55	25%	55%	6.5%	45%	45 - 67
Young	100 - 300	0.15	Stall fed	0.00	0.00	0%	55%	6.5%	10%	23 - 50

[a] Based on estimates for India.

[b] Based on estimates for China.

Source: Gibbs and Johnson (1993).

Annex 10A.2 Data underlying methane default emission factors for Manure Management

This annex presents the data used to develop the default emission factors for methane emissions from Manure Management. The Tier 2 method was implemented with these data to estimate the default emission factors for each livestock category.

Table 10A-4
Manure Management Methane Emission Factor Derivation for Dairy Cows

Annual Average Temperature (°C)		**Manure Management System MCFs**								
		Lagoon[1]	Liquid/ Slurry[1]	Solid Storage	Drylot	Pasture/ Range/ Paddock	Daily Spread	Digester	Burned for Fuel	Other
Cool	10	66%	17%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	11	68%	19%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	12	70%	20%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	13	71%	22%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	14	73%	25%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
Temp	15	74%	27%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	16	75%	29%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	17	76%	32%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	18	77%	35%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	19	77%	39%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	20	78%	42%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	21	78%	46%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	22	78%	50%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	23	79%	55%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	24	79%	60%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	25	79%	65%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
Warm	26	79%	71%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%
	27	80%	78%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%
	28	80%	80%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%

Region	**Dairy Cow Characteristics**			**Manure Management System Usage (MS%)**								
	Mass[a] kg	**B_o**[b] $m^3 CH_4$/kg VS	**VS**[c] kg/hd/day									
North America[d]	604	0.24	5.4	15.0%	27.0%	26.3%	0.0%	10.8%	18.4%	0.0%	0.0%	2.6%
Western Europe	600	0.24	5.1	0.0%	35.7%	36.8%	0.0%	20.0%	7.0%	0.0%	0.0%	0.5%
Eastern Europe	550	0.24	4.5	0.0%	17.5%	60.0%	0.0%	18.0%	2.5%	0.0%	0.0%	2.0%
Oceania	500	0.24	3.5	16.0%	1.0%	0.0%	0.0%	76.0%	8.0%	0.0%	0.0%	0.0%
Latin America	400	0.13	2.9	0.0%	1.0%	1.0%	0.0%	36.0%	62.0%	0.0%	0.0%	0.0%
Africa	275	0.13	1.9	0.0%	0.0%	1.0%	0.0%	83.0%	5.0%	0.0%	6.0%	4.0%
Middle East	275	0.13	1.9	0.0%	1.0%	2.0%	0.0%	80.0%	2.0%	0.0%	17.0%	0.0%
Asia	350	0.13	2.8	4.0%	38.0%	0.0%	0.0%	20.0%	29.0%	2.0%	7.0%	0.0%
Indian Subcontinent	275	0.13	2.6	0.0%	1.0%	0.0%	0.0%	27.0%	19.0%	1.0%	51.0%	0.0%

Emission Factors
kg CH_4 per head per year

Cool					**Temperate**											**Warm**		
10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
48	50	53	55	58	63	65	68	71	74	78	81	85	89	93	98	105	110	112
21	23	25	27	29	34	37	40	43	47	51	55	59	64	70	75	83	90	92
11	12	13	14	15	20	21	22	23	25	27	28	30	33	35	37	42	45	46
23	24	25	26	26	27	28	28	28	29	29	29	29	29	30	30	31	31	31
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3
9	10	10	11	12	13	14	15	16	17	18	20	21	23	24	26	28	31	31
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	6

[a] Average dairy cow mass for each region (default estimates are ±10%)

[b] B_o estimates are ±15%

[c] Average VS production per head per day for the average dairy cow (default estimates are ±20%)

[d] For North America, "Other" manure management system MCFs represent deep pits, which have the same MCF values as Liquid/Slurry.

Emission Factors (EF) for each region are calculated based on eq.10.23.

[1] Lagoon and Liquid/Slurry MCFs are calculated based on the van't Hoff-Arrhenius equation relating temperature to biological activity. Lagoon MCFs are also calculated based on longer (up to a year) retention times. [Mangino, et. al (2001)]

Sources: For North America, dairy cow mass values are from Safley (2000) and VS values are estimated based on an analysis of feed data from Petersen et.al (2003). North American manure management system usage values are estimated using data from the 1992 and 1997 USDA's Census of Agriculture and National Animal Health Monitoring System Reports. B_o values are from Morris (1976) and Bryant, et.al. (1976). For Western and Eastern Europe manure management system usage, mass and VS values based on the analysis of national GHG inventories of Annex I countires submitted to the secretariat UNFCCC in 2004. For the rest of the world, the detailed information for dairy cows are developed in Gibbs and Johnson (1993), and manure management system usage and B_o estimates are from Safley et. al (1992). Methane conversion factor data are from Woodbury and Hashimoto (1993). MCFs for lagoons and liquid/slurry systems are based on data obtained from an analysis of these systems in the United States.

Table 10A-5
Manure Management Methane Emission Factor Derivation for Other Cattle

Annual Average Temperature (°C)		Manure Management System MCFs								
		Lagoon[1]	Liquid/ Slurry[1]	Solid Storage	Drylot	Pasture/ Range/ Paddock	Daily Spread	Digester	Burned for Fuel	Other
Cool	10	66%	17%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	11	68%	19%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	12	70%	20%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	13	71%	22%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	14	73%	25%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
Temp	15	74%	27%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	16	75%	29%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	17	76%	32%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	18	77%	35%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	19	77%	39%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	20	78%	42%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	21	78%	46%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	22	78%	50%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	23	79%	55%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	24	79%	60%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	25	79%	65%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
Warm	26	79%	71%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%
	27	80%	78%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%
	28	80%	80%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%

Region	Other Cattle Characteristics			Manure Management System Usage (MS%)								
	Mass[a]	B_o[b]	VS[c]									
	kg	$m^3 CH_4$/kg VS	kg/hd/day									
North America	389	0.19	2.4	0.0%	0.2%	0.0%	18.4%	81.5%	0.0%	0.0%	0.0%	0.0%
Western Europe	420	0.18	2.6	0.0%	25.2%	39.0%	0.0%	32.0%	1.8%	0.0%	0.0%	2.0%
Eastern Europe	391	0.17	2.7	0.0%	22.5%	44.0%	0.0%	20.0%	0.0%	0.0%	0.0%	13.5%
Oceania	330	0.17	3.0	0.0%	0.0%	0.0%	9.0%	91.0%	0.0%	0.0%	0.0%	0.0%
Latin America	305	0.1	2.5	0.0%	0.0%	0.0%	0.0%	99.0%	0.0%	0.0%	0.0%	1.0%
Africa	173	0.1	1.5	0.0%	0.0%	0.0%	1.0%	95.0%	1.0%	0.0%	3.0%	0.0%
Middle East	173	0.1	1.5	0.0%	0.0%	0.0%	1.0%	79.0%	2.0%	0.0%	17.0%	2.0%
Asia	319	0.1	2.3	0.0%	0.0%	0.0%	46.0%	50.0%	2.0%	0.0%	2.0%	0.0%
Indian Subcontinent	110	0.1	1.4	0.0%	1.0%	0.0%	4.0%	22.0%	20.0%	1.0%	53.0%	0.0%

Emission Factors
kg CH_4 per head per year

Cool					Temperate											Warm		
10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
6	7	7	8	8	10	11	12	13	14	15	16	17	18	20	21	24	25	26
6	6	7	7	8	9	10	11	11	12	13	14	15	16	18	19	21	23	23
1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

[a] Average other cattle mass for each region (default estimates are ±25%)

[b] B_o estimates are ±15%

[c] Average VS production per head per day for the average non-dairy cow (default estimates are ±35%)

Emission Factors (EF) for each region are calculated based on eq.10.23.

[1] Lagoon and Liquid/Slurry MCFs are calculated based on the van't Hoff-Arrhenius equation relating temperature to biological activity. Lagoon MCFs are also calculated based on longer (up to a year) retention times. [Mangino, et. al (2001)]

Sources: For North America, other cattle mass are from Safley (2000) and USDA's Agricultural Waste Management Field Handbook and VS values are estimated based on an analysis of feed data from Petersen, et.al (2003). North American manure management system usage values are estimated using data from the 1992 and 1997 USDA's Census of Agriculture and National Animal Health Monitoring System Reports. B_o data are values reported in Hashimoto (1981). For Western and Eastern Europe manure management system usage, average mass, B_o, and VS values based on the analysis of national GHG inventories of Annex I countires submitted to the secretariat UNFCCC in 2004. For the rest of the world, the detailed information for cattle are developed in Gibbs and Johnson (1993), and manure management system usage and B_o estimates are from Safley et. al (1992). Methane conversion factor data are from Woodbury and Hashimoto (1993). MCFs for lagoons and liquid/slurry systems are based on data obtained from an analysis of these systems in the United States.

Table 10A-6
Manure Management Methane Emission Factor Derivation for Buffalo

Annual Average Temperature (°C)		**Manure Management System MCFs**								
		Lagoon[1]	Liquid/ Slurry[1]	Solid Storage	Drylot	Pasture/ Range/ Paddock	Daily Spread	Digester	Burned for Fuel	Other
Cool	10	66%	17%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	11	68%	19%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	12	70%	20%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	13	71%	22%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
	14	73%	25%	2.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
Temp	15	74%	27%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	16	75%	29%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	17	76%	32%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	18	77%	35%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	19	77%	39%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	20	78%	42%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	21	78%	46%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	22	78%	50%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	23	79%	55%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	24	79%	60%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
	25	79%	65%	4.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
Warm	26	79%	71%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%
	27	80%	78%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%
	28	80%	80%	5.0%	2.0%	2.0%	1.0%	10.0%	10.0%	1.0%

Region	**Buffalo Characteristics**			**Manure Management System Usage (MS%)**								
	Mass[a] kg	**B$_o$** m^{3}CH$_4$/kg VS	**VS**[b] kg/hd/day									
North America		(not applicable)						(not applicable)				
Western Europe	380	0.1	3.9	0%	20%	0%	79%	0%	0%	0%	0%	0%
Eastern Europe	380	0.1	3.9	0%	24%	0%	0%	29%	0%	0%	0%	47%
Oceania		(not applicable)						(not applicable)				
Latin America	380	0.1	3.9	0%	0%	0%	0%	99%	0%	0%	0%	1%
Africa		(not applicable)						(not applicable)				
Middle East	380	0.1	3.9	0%	0%	0%	0%	20%	19%	0%	42%	19%
Asia	380	0.1	3.9	0%	0%	0%	41%	50%	4%	0%	5%	0%
Indian Subcontinent	295	0.1	3.1	0%	0%	0%	4%	19%	21%	1%	55%	0%

Emission Factors
kg CH$_4$ per head per year

Region	**Cool**					**Temperate**											**Warm**		
	10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
North America	Not Applicable																		
Western Europe	4	4	5	5	5	6	7	7	8	9	9	10	11	12	13	14	15	16	17
Eastern Europe	5	5	5	6	6	7	8	8	9	10	11	11	12	13	15	16	17	19	19
Oceania	Not Applicable																		
Latin America	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
Africa	Not Applicable																		
Middle East	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Asia	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Indian Subcontinent	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5	5

[a] Average buffalo mass for each region

[b] Average VS production per head per day for the average buffalo

Emission Factors (EF) for each region are calculated based on eq.10.23.

[1] Lagoon and Liquid/Slurry MCFs are calculated based on the van't Hoff-Arrhenius equation relating temperature to biological activity. Lagoon MCFs are also calculated based on longer (up to a year) retention times. [Mangino, et. al (2001)]

Sources: The detailed information for buffalo are developed in Gibbs and Johnson (1993),and manure management system usage and B$_o$ estimates are from Safley et. al (1992). Methane conversion factor data are from Woodbury and Hashimoto (1993). MCFs for lagoons and liquid/slurry systems are based on data obtained from an analysis of these systems in the United States.

Table 10A-7
Manure Management Methane Emission Factor Derivation for Market Swine

Annual Average Temperature (°C)		Manure Management System MCFs								
		Lagoon[1]	Liquid/ Slurry[1]	Solid Storage	Drylot	Pit <1 month	Pit >1 month	Daily Spread	Digester	Other
Cool	10	66%	17%	2.0%	1.0%	3.0%	17%	0.1%	10.0%	1.0%
	11	68%	19%	2.0%	1.0%	3.0%	19%	0.1%	10.0%	1.0%
	12	70%	20%	2.0%	1.0%	3.0%	20%	0.1%	10.0%	1.0%
	13	71%	22%	2.0%	1.0%	3.0%	22%	0.1%	10.0%	1.0%
	14	73%	25%	2.0%	1.0%	3.0%	25%	0.1%	10.0%	1.0%
Temp	15	74%	27%	4.0%	1.5%	3.0%	27%	0.5%	10.0%	1.0%
	16	75%	29%	4.0%	1.5%	3.0%	29%	0.5%	10.0%	1.0%
	17	76%	32%	4.0%	1.5%	3.0%	32%	0.5%	10.0%	1.0%
	18	77%	35%	4.0%	1.5%	3.0%	35%	0.5%	10.0%	1.0%
	19	77%	39%	4.0%	1.5%	3.0%	39%	0.5%	10.0%	1.0%
	20	78%	42%	4.0%	1.5%	3.0%	42%	0.5%	10.0%	1.0%
	21	78%	46%	4.0%	1.5%	3.0%	46%	0.5%	10.0%	1.0%
	22	78%	50%	4.0%	1.5%	3.0%	50%	0.5%	10.0%	1.0%
	23	79%	55%	4.0%	1.5%	3.0%	55%	0.5%	10.0%	1.0%
	24	79%	60%	4.0%	1.5%	3.0%	60%	0.5%	10.0%	1.0%
	25	79%	65%	4.0%	1.5%	3.0%	65%	0.5%	10.0%	1.0%
Warm	26	79%	71%	5.0%	2.0%	30.0%	71%	1.0%	10.0%	1.0%
	27	80%	78%	5.0%	2.0%	30.0%	78%	1.0%	10.0%	1.0%
	28	80%	80%	5.0%	2.0%	30.0%	80%	1.0%	10.0%	1.0%

Region	Market Swine Characteristics			Manure Management System Usage (MS%)								
	Mass[a]	**B_o**[b]	**VS**[c]									
	kg	$m^3 CH_4$/kg VS	kg/hd/day									
North America	46	0.48	0.27	32.8%	18.5%	4.2%	4.0%	0.0%	40.6%	0.0%	0.0%	0.0%
Western Europe	50	0.45	0.3	8.7%	0.0%	13.7%	0.0%	2.8%	69.8%	2.0%	0.0%	3.0%
Eastern Europe	50	0.45	0.3	3.0%	0.0%	42.0%	0.0%	24.7%	24.7%	0.0%	0.0%	5.7%
Oceania	45	0.45	0.28	54.0%	0.0%	3.0%	15.0%	0.0%	0.0%	0.0%	0.0%	28.0%
Latin America	28	0.29	0.3	0.0%	8.0%	10.0%	41.0%	0.0%	0.0%	2.0%	0.0%	40.0%
Africa	28	0.29	0.3	0.0%	6.0%	6.0%	87.0%	1.0%	0.0%	0.0%	0.0%	0.0%
Middle East	28	0.29	0.3	0.0%	14.0%	0.0%	69.0%	0.0%	17.0%	0.0%	0.0%	0.0%
Asia	28	0.29	0.3	0.0%	40.0%	0.0%	54.0%	0.0%	0.0%	0.0%	7.0%	0.0%
Indian Subcontinent	28	0.29	0.3	9.0%	22.0%	16.0%	30.0%	3.0%	0.0%	9.0%	8.0%	3.0%

[a] Average marker swine mass for each region (default estimates are ±20%)

[b] B_o estimates are ±15%

[c] Average VS production per head per day for the average market swine (default estimates are ±25%)

Emission Factors (EF) for each region are calculated based on eq.10.23.

[1] Lagoon and Liquid/Slurry MCFs are calculated based on the van't Hoff-Arrhenius equation relating temperature to biological activity. Lagoon MCFs are also calculated based on longer (up to a year) retention times. [Mangino, et. al (2001)]

Sources: For North America, mass, VS, and B_o values are from Safley (2000), USDA's Agricultural Waste Management Field Handbook, and Hashimoto (1984), respectively. North American manure management system usage data are estimated using data from the 1992 and 1997 USDA's Census of Agriculture and National Animal Health Monitoring System Reports. For Western and Eastern Europe manure management system usage, mass of animals, B_o and VS values based on the analysis of national GHG inventories of Annex I countires submitted to the secretariat UNFCCC in 2004. For the rest of the world, swine feed intake data are from Crutzen et. al (1986), and manure management system usage and B_o estimates are from Safley et. al (1992). Methane conversion factor data are from Woodbury and Hashimoto (1993). MCFs for lagoons and liquid/slurry systems are based on data obtained from an analysis of these systems in the United States.

Emission Factors
kg CH_4 per head per year

Cool					**Temperate**											**Warm**		
10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
10	11	11	12	12	13	13	14	15	15	16	17	18	18	19	20	22	23	23
6	6	7	7	8	9	9	10	11	11	12	13	14	15	16	18	19	21	21
3	3	3	3	3	4	4	4	4	5	5	5	6	6	6	7	10	10	10
11	11	12	12	12	13	13	13	13	13	13	13	13	13	13	13	13	13	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
1	1	1	2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6
2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6	6	7	7
2	2	3	3	3	3	3	3	4	4	4	4	4	5	5	5	6	6	6

Table 10A-8
Manure Management Methane Emission Factor Derivation for Breeding Swine

Annual Average Temperature (°C)		Manure Management System MCFs								
		Lagoon[1]	Liquid/ Slurry[1]	Solid Storage	Drylot	Pit <1 month	Pit >1 month	Daily Spread	Digester	Other
Cool	10	66%	17%	2.0%	1.0%	3.0%	17%	0.1%	10.0%	1.0%
	11	68%	19%	2.0%	1.0%	3.0%	19%	0.1%	10.0%	1.0%
	12	70%	20%	2.0%	1.0%	3.0%	20%	0.1%	10.0%	1.0%
	13	71%	22%	2.0%	1.0%	3.0%	22%	0.1%	10.0%	1.0%
	14	73%	25%	2.0%	1.0%	3.0%	25%	0.1%	10.0%	1.0%
Temp	15	74%	27%	4.0%	1.5%	3.0%	27%	0.5%	10.0%	1.0%
	16	75%	29%	4.0%	1.5%	3.0%	29%	0.5%	10.0%	1.0%
	17	76%	32%	4.0%	1.5%	3.0%	32%	0.5%	10.0%	1.0%
	18	77%	35%	4.0%	1.5%	3.0%	35%	0.5%	10.0%	1.0%
	19	77%	39%	4.0%	1.5%	3.0%	39%	0.5%	10.0%	1.0%
	20	78%	42%	4.0%	1.5%	3.0%	42%	0.5%	10.0%	1.0%
	21	78%	46%	4.0%	1.5%	3.0%	46%	0.5%	10.0%	1.0%
	22	78%	50%	4.0%	1.5%	3.0%	50%	0.5%	10.0%	1.0%
	23	79%	55%	4.0%	1.5%	3.0%	55%	0.5%	10.0%	1.0%
	24	79%	60%	4.0%	1.5%	3.0%	60%	0.5%	10.0%	1.0%
	25	79%	65%	4.0%	1.5%	3.0%	65%	0.5%	10.0%	1.0%
Warm	26	79%	71%	5.0%	2.0%	30.0%	71%	1.0%	10.0%	1.0%
	27	80%	78%	5.0%	2.0%	30.0%	78%	1.0%	10.0%	1.0%
	28	80%	80%	5.0%	2.0%	30.0%	80%	1.0%	10.0%	1.0%

Region	Breeding Swine Characteristics			Manure Management System Usage (MS%)								
	Mass[a]	**B_o**[b]	**VS**[c]									
	kg	$m^3 CH_4$/kg VS	kg/hd/day									
North America	198	0.48	0.5	32.8%	18.5%	4.2%	4.0%	0.0%	40.6%	0.0%	0.0%	0.0%
Western Europe	198	0.45	0.46	8.7%	0.0%	13.7%	0.0%	2.8%	69.8%	2.0%	0.0%	3.0%
Eastern Europe	180	0.45	0.5	3.0%	0.0%	42.0%	0.0%	24.7%	24.7%	0.0%	0.0%	5.7%
Oceania	180	0.45	0.5	54.0%	0.0%	3.0%	15.0%	0.0%	0.0%	0.0%	0.0%	28.0%
Latin America	28	0.29	0.3	0.0%	8.0%	10.0%	41.0%	0.0%	0.0%	2.0%	0.0%	40.0%
Africa	28	0.29	0.3	0.0%	6.0%	6.0%	87.0%	1.0%	0.0%	0.0%	0.0%	0.0%
Middle East	28	0.29	0.3	0.0%	14.0%	0.0%	69.0%	0.0%	17.0%	0.0%	0.0%	0.0%
Asia	28	0.29	0.3	0.0%	40.0%	0.0%	54.0%	0.0%	0.0%	0.0%	7.0%	0.0%
Indian Subcontinent	28	0.29	0.3	9.0%	22.0%	16.0%	30.0%	3.0%	0.0%	9.0%	8.0%	3.0%

[a] Average breed swine mass for each region (default estimates are ±20%)

[b] B_o estimates are ±15%

[c] Average VS production per head per day for the average breed swine (default estimates are ±25%)

Emission Factors (EF) for each region are calculated based on eq.10.23.

[1] Lagoon and Liquid/Slurry MCFs are calculated based on the van't Hoff-Arrhenius equation relating temperature to biological activity. Lagoon MCFs are also calculated based on longer (up to a year) retention times. [Mangino, et. al (2001)]

Sources: For North America, mass, VS, and B_o values are from Safley (2000), USDA's Agricultural Waste Management Field Handbook, and Hashimoto (1984), respectively. North American manure management system usage data are estimated using data from the 1992 and 1997 USDA's Census of Agriculture and National Animal Health Monitoring System Reports. For Western and Eastern Europe manure management system usage, mass of animals, B_o and VS values based on the analysis of national GHG inventories of Annex I countires submitted to the secretariat UNFCCC in 2004. For the rest of the world, swine feed intake data are from Crutzen et. al (1986), and manure management system usage and B_o estimates are from Safley et. al (1992). Methane conversion factor data are from Woodbury and Hashimoto (1993). MCFs for lagoons and liquid/slurry systems are based on data obtained from an analysis of these systems in the United States.

Emission Factors
kg CH_4 per head per year

Cool					Temperate											Warm		
10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
19	20	21	22	23	24	26	27	28	29	31	32	34	35	37	39	41	44	45
9	10	10	11	12	13	14	15	16	17	19	20	22	23	25	27	29	32	33
4	5	5	5	5	6	7	7	7	8	8	9	9	10	11	12	16	17	17
20	20	21	21	22	22	23	23	23	23	23	24	24	24	24	24	24	24	24
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
1	1	1	2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6
2	2	2	2	2	3	3	3	3	4	4	4	5	5	5	6	6	7	7
2	2	3	3	3	3	3	3	4	4	4	4	4	5	5	5	6	6	6

Table 10A-9
Manure Management Methane Emission Factor Derivation

Animal			Sheep		Goats		Camels		Horses		Mule/Asses		Poultry					
													Developed					
		Country	Developed	Developing	Developed	Developing	Developed	Developing	Developed	Developing	Developed	Developing	Layers (dry)	Layers (wet)	Broilers	Turkeys	Ducks	Developing
Animal Characteristics																		
		Mass (kg)	48.5	28	38.5	30	217	217	377	238	130	130	1.8	1.8	0.9	6.8	2.7	NR
		Digest (%)	0.60	0.5	0.6	0.5	0.5	0.5	0.7	0.7	0.7	0.7	NR	NR	NR	NR	NR	NR
		Intake/d (kg Feed)	1.08	0.7	0.76	0.76	5.42	5.42	5.96	5.96	3.25	3.25	NR	NR	NR	NR	NR	NR
		% Ash (Dry Basis)	8.00	8	8	8	8	8	4	4	4	4	NR	NR	NR	NR	NR	NR
		VS/day (kg VS)	0.40	0.32	0.3	0.35	2.49	2.49	2.13	1.72	0.94	0.94	0.02	0.02	0.01	0.07	0.02	0.02
		B_o (m3/kg VS)	0.19	0.13	0.18	0.13	0.26	0.21	0.3	0.26	0.33	0.26	0.39	0.39	0.36	0.36	0.36	0.24
Manure Management System MCFs																		
Annual Average Temperature (°C)	**Cool**	**10**	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	65%	1.5%	1.5%	1.0%	1.0%
		11	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	68%	1.5%	1.5%	1.0%	1.0%
		12	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	70%	1.5%	1.5%	1.0%	1.0%
		13	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	73%	1.5%	1.5%	1.0%	1.0%
		14	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	74%	1.5%	1.5%	1.0%	1.0%
	Temperate	**15**	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	75%	1.5%	1.5%	1.5%	1.5%
		16	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	76%	1.5%	1.5%	1.5%	1.5%
		17	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	76%	1.5%	1.5%	1.5%	1.5%
		18	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	77%	1.5%	1.5%	1.5%	1.5%
		19	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	78%	1.5%	1.5%	1.5%	1.5%
		20	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	78%	1.5%	1.5%	1.5%	1.5%
		21	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	78%	1.5%	1.5%	1.5%	1.5%
		22	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	78%	1.5%	1.5%	1.5%	1.5%
		23	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	79%	1.5%	1.5%	1.5%	1.5%
		24	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	79%	1.5%	1.5%	1.5%	1.5%
		25	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	80%	1.5%	1.5%	1.5%	1.5%
	Warm	**26**	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	1.5%	80%	1.5%	1.5%	2.0%	2.0%
		27	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	1.5%	80%	1.5%	1.5%	2.0%	2.0%
		28	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	1.5%	80%	1.5%	1.5%	2.0%	2.0%
Emission Factors (kg CH_4 per head per year)																		
Annual Average Temperature (°C)	**Cool**	**10**	0.19	0.10	0.13	0.11	1.58	1.28	1.56	1.09	0.76	0.60	0.03	1.13	0.02	0.09	0.02	0.01
		11	0.19	0.10	0.13	0.11	1.58	1.28	1.56	1.09	0.76	0.60	0.03	1.18	0.02	0.09	0.02	0.01
		12	0.19	0.10	0.13	0.11	1.58	1.28	1.56	1.09	0.76	0.60	0.03	1.21	0.02	0.09	0.02	0.01
		13	0.19	0.10	0.13	0.11	1.58	1.28	1.56	1.09	0.76	0.60	0.03	1.26	0.02	0.09	0.02	0.01
		14	0.19	0.10	0.13	0.11	1.58	1.28	1.56	1.09	0.76	0.60	0.03	1.28	0.02	0.09	0.02	0.01
	Temperate	**15**	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.30	0.02	0.09	0.03	0.02
		16	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.31	0.02	0.09	0.03	0.02
		17	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.32	0.02	0.09	0.03	0.02
		18	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.33	0.02	0.09	0.03	0.02
		19	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.35	0.02	0.09	0.03	0.02
		20	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.35	0.02	0.09	0.03	0.02
		21	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.36	0.02	0.09	0.03	0.02
		22	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.36	0.02	0.09	0.03	0.02
		23	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.37	0.02	0.09	0.03	0.02
		24	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.38	0.02	0.09	0.03	0.02
		25	0.28	0.15	0.20	0.17	2.37	1.92	2.34	1.64	1.14	0.90	0.03	1.38	0.02	0.09	0.03	0.02
	Warm	**26**	0.37	0.20	0.26	0.22	3.17	2.56	3.13	2.19	1.52	1.20	0.03	1.38	0.02	0.09	0.03	0.02
		27	0.37	0.20	0.26	0.22	3.17	2.56	3.13	2.19	1.52	1.20	0.03	1.39	0.02	0.09	0.03	0.02
		28	0.37	0.20	0.26	0.22	3.17	2.56	3.13	2.19	1.52	1.20	0.03	1.39	0.02	0.09	0.03	0.02

NR = Not reported.

Emission factors, except for poultry, were developed from feed intake values and feed digestibilities used to develop the enteric fermentation emission factors (see Appendix 10A.1). MCFs and B_o values are reported in Woodbury and Hashimoto (1993). All manure except for Layers (wet) is assumed to be managed in dry systems, which is consistent with the manure management system usage reported in Woodbury and Hashimoto (1993). Poultry for developed countries was subdivided into five categories. Layers (dry) represent layers in a "without bedding" waste management system; Layers (wet) represent layers in an anaerobic lagoon waste managemnet system.

Estimates of animal mass are ±30%, VS values are ±50% and B_o values are ±15%

TABLE 10A-9 (CONTINUED)
MANURE MANAGEMENT METHANE EMISSION FACTOR DERIVATION FOR OTHER ANIMALS

Animal	Animal Characteristics			Manure management system MCF	Emission factors (kg CH_4 head^{-1} yr^{-1})
	Mass (kg)	VS (kg VS day^{-1})	Bo (m^3 kg VS)		
Deer [a]	NR	NR	NR	NR	0.22
Reindeer [b]	NR	0.39	0.19	2.0%	0.36
Rabbits [c]	1.60	0.10	0.32	1.0%	0.08
Fur-bearing animals [b]	NR	0.14	0.25	8.0%	0.68
Ostrich [b]	NR	1.16	0.25	8.0%	5.67

[a] Sneath (1997) cited in the GHG inventory of United Kingdom.

[b] Estimations of Agricultural University of Norway, Institute of Chemistry and Biotechnology, Section for Microbiology.

[c] Data obtained from GHG inventory of Italy, 2004.

NR = not reported

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SECTION 10.5 NITROUS OXIDE EMISSIONS FROM MANURE MANAGEMENT

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