CHAPTER 10

EMISSIONS FROM LIVESTOCK AND MANURE MANAGEMENT

Authors:

Olga Gavrilova (Estonia), Adrian Liep (Germany), Carlos Alfredo Gomez Bravo (Peru), Barbara Amon (Germany), Rolando Barahonar Rosales (Honduras), Agustin del Prado (Spain), Magda Aparecida de Lima (Brazil), Walter Oyhancabal (Uruguay) and Tony John van der Weerden (New Zealand), and Yeni Widiawati (Indonesia)

Contributing Authors:

Andre Bannink (Netherlands), Karen Beauchemin (Canada), Harry Clark (New Zealand), April Leytem (USA), Ermias Kebreab (USA), Carolyn Opio, Martin Ngwabie (Cameroon), Andy VanderZaag (Canada), Theun Vellinga,

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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).

In calculating agricultural emissions, it is important to establish consistency among the different emission sources. Key drivers of emissions such as animal weight and productivity must be treated using the same parameters for emissions of enteric and manure management methane, as well as N_2O from manure management. Further, Section 10.5.4 discusses the coordination between N_2O emissions from Manure Management and Managed Soils. Emissions of N_2O from nitrogen excretion should be assessed following a nitrogen mass flow approach which is further explained in Section 10.5.6 and illustrated in Figure 10.5.

10.2 LIVESTOCK POPULATION AND FEED CHARACTERISATION

10.2.1 Steps to define categories and subcategories of livestock

10.2.2 Choice of method

This section contains updated guidance

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 vary 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:

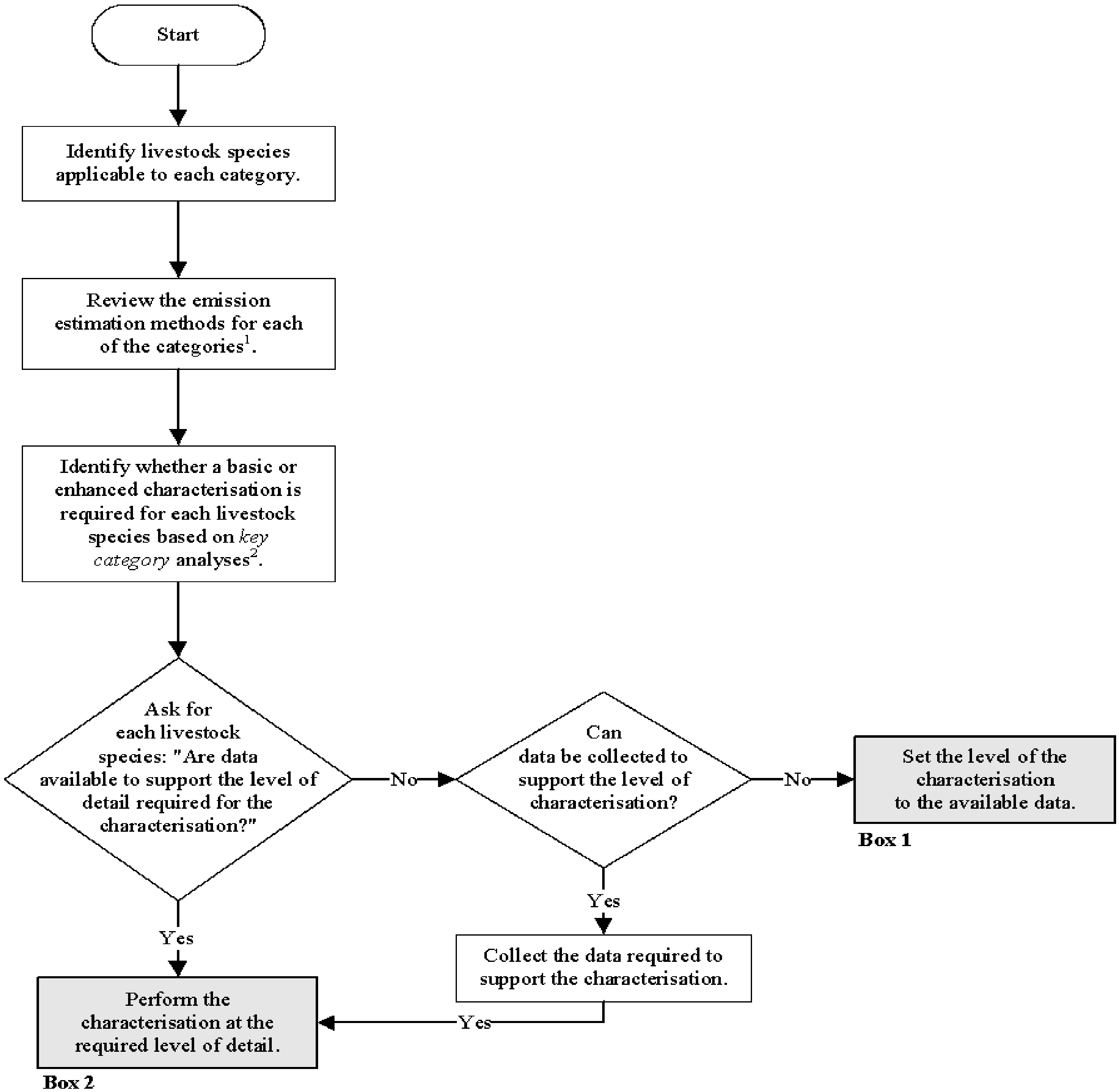
AAP = annual average population

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 grown and slaughtered over the course of a year would greatly overestimate the population, as it would assume each 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:

$$\text{Annual average population} = 60 \text{ days} \bullet 60{,}000 / 365 \text{ days / yr} = 9{,}863 \text{ chickens}$$

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.

Consideration of differing Productivity Classes (Tier 1B)

In certain countries agricultural production systems may be transitioning from low productivity local subsistence systems to higher productivity systems aimed at fulfilling national and export commodity markets or may simply have dual agricultural systems, with coexistence of low and high productivity systems. In these cases inventory compilers may wish to use the Tier 1b system in which they are able to better track the transitions and changes of their agricultural systems productivity and related emissions over time.

In this case animal populations may be divided by productivity classes. For each animal category high and low productivity classes may be defined according to the following characteristics; Tier 1, per head emission factors have been developed for use with basic population estimates separated by low and high productivity classes according to the following definitions.

Definitions of High and Low Productivity Systems[1]

Dairy Cattle 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 (first lactation and beyond) 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 in the developing world, the dairy cow population is comprised of two well-defined segments:

- **High-productivity systems** are based on animal feeding systems adapted for medium- or large-scale (herd size) farms and high-yielding dairy cows that are concentrated in confinement production systems or grazing with supplements or on improved pastures. The farms are 100-percent market oriented for commercial milk production, sale and export; Cows are genetically improved for milk production and either be purebred or crossbred (FAO *et al.* 2014).
- **Low productivity systems** are based on animal feeding systems occurring in small-scale (herd size), with low-yielding dairy cows, where locally produced roughage (e.g. crop residues) and/or rangelands represents the major source of feed utilized. Cows are not genetically improved for milk production and are either local or introduced breeds and sometimes may be crossbred but should not be confused with multi-purpose cows that may be used for more than one production purpose: milk, meat or draft. Milk production is mostly for local market and local consumption (FAO *et al.* 2014).

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 or fat corrected 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. 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.

Non Dairy cows:

- **High-productivity systems** are based on animal feeding systems adapted for medium- or large-scale (herd size) farms and medium and high-weight gaining animals using locally produced roughage (e.g. high-quality grass) and concentrated in confinement production systems or grazing with supplements or on improved pastures. Animals are genetically improved for commercial meat production in national or export markets and either be purebred or crossbred. Growing cattle may be finished young, under 24 months in "intensive grazing with supplements" or feedlot, and meat is produced for national scale markets and/or export (FAO *et al.* 2014).
- **Low productivity systems** are based on animal feeding systems for small-scale (herd size) low- weight gaining animals, where locally produced roughage (e.g. crop residues) or rangelands represents the major source of feed utilized. Animals are normally not genetically improved for meat production and are either local or introduced

[1] High and low productivity systems are intended to represent situations, particularily in countries under development, where there are very different productions systems, one based on regional low input traditions and other systems that are similar to industrial agricultural systems in developed countries.

breeds, sometimes may be crossbred and can also be used for multiple purposes such as draft or milk for self consumption alone. Meat production goes to local markets (FAO *et al.* 2014).

Other livestock categories

- **High-productivity systems** are based on animal feeding systems for medium- or large-scale (herd size) farms, which are 100 percent market oriented with high level of capital input requirements and high level of overall herd (flock) performance. Feed is purchased from local or international market or intensively produced on farm. Animals are genetically improved for commercial production. The high-productivity systems are common in swine, poultry, goats and sheep production (MacLeod *et al.* 2017). The farming practice and animal breeds associated with high productivity systems of such animals as camels, mules, asses, deer and alpacas refers to production systems established in developed countries as they were described in the *2006 IPCC Guidelines* (MacLeod *et al.* 2017).

- **Low productivity systems** are based on animal feeding systems for small- or medium-scale (herd size), which are mainly driven by local market or by self-consumption, with low capital input requirements and low level of overall herd (fowl) typically using large areas for production. Locally produced feed represents the major source of feed utilized or animals are kept-free range for major part or all of their production cycle, the yield of the activity being linked to the natural fertility of the land and the seasonal production of the pastures. The farming practice and animal breeds associated with low productivity systems of such animals as camels, mules, asses, deer and alpacas refers to production systems established in developing countries as they were described in the *2006 IPCC Guidelines* (MacLeod *et al.* 2017).

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 with 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.

TABLE 10.1
REPRESENTATIVE LIVESTOCK CATEGORIES[1,2]

Main categories	Production categories Tier 1b	Subcategories
Mature Dairy Cow or Mature Dairy Buffalo	High Productivity Systems	High-producing cows that have calved at least once and are used principally for milk production
	Low Productivity Systems	Low-producing cows that have calved at least once and are used principally for milk production
Other Mature Cattle or Mature Non-dairy Buffalo	High Productivity Systems	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.
	Low Productivity Systems	Females:
		· Cows that may be used for more than one production purpose: milk, meat, draft
		Males:
		· Bulls used principally for draft power
Growing Cattle or Growing Buffalo	High Productivity Systems	· Calves pre-weaning
		· Replacement dairy heifers
		· Growing / fattening cattle or buffalo post-weaning
		· Feedlot-fed cattle on diets containing > 85 % concentrates
	Low Productivity Systems	· Calves pre-weaning
		· Growing / fattening cattle or buffalo post-weaning
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	
Goats	Dairy Does	
	Mature does	
	Yearlings	
	Bucks	
	Kids (<1 yr)	
Mature Swine	High Productivity	· Sows in gestation

	Systems	· Sows which have farrowed and are nursing young
		· Boars that are used for breeding purposes
	Low Productivity Systems	· Sows in gestation
		· Sows which have farrowed and are nursing young
		· Boars that are used for breeding purposes
Growing Swine	High Productivity Systems	· Nursery
		· Finishing
		· Gilts that will be used for breeding purposes
		· Growing boars that will be used for breeding purposes
	Low Productivity Systems	· Growing / fattening swine
		· Gilts/boars will be used for breeding purposes
Chickens	High Productivity Systems	· Broiler chickens grown for producing meat in confinement systems · Breeder Broiler chickens grown in confinement systems
		· 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
	Low Productivity Systems	· Chickens under free-range conditions for egg or meat production
Turkeys	High Productivity Systems	· Breeding turkeys in confinement systems
		· Turkeys grown for producing meat in confinement systems
		· Turkeys under free-range conditions for meat production
	Low Productivity 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 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.

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 or kg per day); and
- methane conversion factor (Ym) 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)[2];
- feeding situation: confined, grazing, pasture conditions;
- milk production per day (kg/day), fat and protein content;
- 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
- digestibility of feed, expressed as the percentage of digestible energy in feed gross energy (DC, %)
- crude protein in diet (CP,%).

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., mega Joules (MJ) per day) or dry matter (e.g., kilograms (kg)) consumed 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 the 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 required from the animal performance and diet data for each subcategory.

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

[3] This is only relevant for mature females.

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 mature sheep, the yearly average weight for each animal category (e.g., mature beef cows) is needed. For young animals, 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' (AAC 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 is intermediate to the definitions given, 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 value. 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 10.2 during the cold months 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 leads to a greater methane emissions. The Nutrient Requirements of Beef Cattle, 8th Revised Edition (2016) cautions that the general response to cold temperature can vary with thermal susceptibility of the animal, acclimation, and diet. Thus, Eq. 10.2 may not be applicable for adapted animals, or for those protected by wind-breaks or shelter during cold weather.

- **Average daily milk production (kg day^{-1}):** These data are for milking ewes, milking does, 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 seasonal production divided by number of days per season. If using seasonal production data, the emission factor must be developed for seasonal period.
- **Fat content (%):** Average fat content of milk is required for lactating cows, buffalo, sheep, and goats producing milk for human consumption.
- **Protein content (%):** Average protein content of milk is required for lactating cows, buffalo, sheep, and goats producing milk for human consumption.
- **Percent of females that give birth in a year:** This is collected only for mature cattle, buffalo, sheep and goats
- **Number of off spring produced per year:** This is relevant to female livestock that have multiple births per year (e.g., ewes).
- **Weaning age of calves**: Prior to weaning calves and the development of an active rumen, calves do not emit and emissions are associated with increases in energy requirements by the lactating cow. Countries should estimate the establishment of rumen function based on typicall weaning age of the national or regional herd
- **Feed digestibility (DC):** The portion of gross energy (GE) in the feed not excreted in the faeces is known as digestible energy expressed as a percentage (%). Feed digestibility is commonly expressed as a percentage of GE or as TDN (total digestible nutrients). The percentage of feed that is not digested represents the % of GE intake that will be excreted as faeces. Typical digestibility (DC) 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; 55-80% for good pastures, good preserved forages, crop by-products and grain supplemented forage-based diets; and 72-85% for grain-based diets fed in feedlots. Variation in diet digestibility results directly in major variation in the estimated amount of feed needed to meet animal requirements and consequently is a main cause of variation in associated methane emissions and in the amounts of manure excreted (next to variation in yield of methane per unit of digested GE as explained further in chapter 10.3).

  A low digestibility feed will lead to lower feed intake and consequently reduced growth but at the same time a larger production of associated methane per unit of growth or production. Conversely, feeds with high digestibility will often result in higher feed intake and increased growth but at the same time a smaller amount of feed required per unit of growth and consequently lower associated methane production per unit growth or production. A factor directly affecting feed digestibility is the rate of passage of feed in the digestive tract, in particular in high productivity dairy cows (NRC 2001; Nousiainen *et al.* 2009) with direct impact on methane production as well, though in current Tier 2 methodology this impact is resolved through the selection of appropriate methane conversion rates instead of appropriate digestibility estimates (see Section 10.3.2).

  A 10% error in estimating DC will be magnified to 12 to 20% when estimating methane emissions and even more (20 to 45%) for amounts of manure excreted (volatile solids). It is important to note that feed requirements, feed digestibility, production and growth, and yield of methane from digested GE (explained further in chapter 10.3) are co-dependent phenomena.

  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 hot weather or dry season. Due to significant variation, digestibility values 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 feed content of neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein, crude fat, ash and the presence of anti-nutritional factors (e.g., alkaloids, phenolics). 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 DC to be predicted as defined in the last dairy National Research Council (2008) publication. The concentration of crude protein in the feed can be used in the process of estimating nitrogen excretion (Section 10.5.2). Accurate estimation of the crude fat content of feed is important, especially in the case of high-fat feeds, for accurate estimation of the GE content in feed, which is needed to calculate feed intake needed to achieve GE requirements (Section 10.2.2.).

- **Protein content in diet (CP, %) –** the total amount of protein present in animal diet. It is determined by analysing the nitrogen content in animal feed and multiplying by 6.25. The data on CP,% is required for the calculation of N excretion using a Tier 2 methodologies.
- **Average annual wool production per sheep and goats (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. For goats this is only applicable if the country has relevant numbers of fibre-producing goats.

TABLE 10.2
REPRESENTATIVE FEED DIGESTIBILITY FOR VARIOUS LIVESTOCK CATEGORIES

Main categories	Class	Digestibility (DC as %)
Swine[1]	Mature Swine – confinement	70 - 80
	Growing Swine - confinement	80 - 90
	Swine – free range	50 - 70
Cattle and other ruminants	Feedlot animals fed with > 85% concentrate or high-grain diet;	72 - 85
	Pasture / mixed-diet fed animals;	55 - 80
	Animals fed – low quality forage	45 - 55
Poultry[1]	Broiler Chickens –confinement	85 - 93
	Layer Hens – confinement	70 - 80
	Poultry – free range	55 - 90 [1]
	Turkeys – confinement	85 - 93
	Geese – confinement	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 the amount of energy (MJ/day) animal needs for maintenance and for 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 and goats 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 AND GOATS

Metabolic functions and other estimates	Equations for cattle and buffalo	Equations for sheep and goats
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 and goats based on AFRC (1993; 1995).
NA means 'not applicable'.
* Applies only to the proportion of females that give birth.

Net energy for maintenance: (NEm) 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: (NEa) 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 NEa for cattle and buffalo is different from the equation used for sheep and goats. Both equations are empirical with different definitions for the coefficient Ca.

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^{-}

EQUATION 10.5
NET ENERGY FOR ACTIVITY (FOR SHEEP AND GOATS)

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

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	0.322	All non-lactating cows, steers, heifers and calves
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.
Goats	0.315	

Source: NRC (1996) and AFRC (1993; 1995).

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
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 and goats (unit for C_a = MJ d^{-1} kg^{-1})		
Housed ewes	Animals are confined due to pregnancy in final trimester (50 days).	0.0096
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.	0.024
Housed fattening lambs	Animals are housed for fattening.	0.0067
Lowland goats	Animals walk and graze in lowland pasture	0.019
Hill and mountain goats	Animals graze in open range land or hilly terrain and expend significant energy to acquire feed.	0.024

***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 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 AND GOATS)

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

Where:

NEg = net energy needed for growth, MJ day-1

WGlamb/kid (goats) = the weight gain (BWf – BWi), kg yr^{-1}

BWi = the live bodyweight at weaning, kg

BWf = 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 AND GOATS

Animal species/category	a (MJ kg^{-1})	b (MJ kg^{-1})
Intact males (Sheep)	2.5	0.35
Castrates (Sheep)	4.4	0.32
Females (Sheep)	2.1	0.45
Goats (all categories)	4.972	0.3274
Source: AFRC (1993; 1995).		

***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)

$$NE_1 = Milk \bullet \left(1.47 + 0.40 \bullet Fat\right)$$

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 increase in 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 AND GOATS (MILK PRODUCTION KNOWN)

$$NE_1 = Milk \bullet EV_{milk}$$

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 EV_{milk} value of 4.6 MJ/kg (sheep) (AFRC 1993; AFRC 1995) and 3 MJ/kg (goats) (AFRC 1998) can be used which corresponds to a milk fat content of 7% and 3.8% by weight for sheep and goats, respectively.

EQUATION 10.10
NET ENERGY FOR LACTATION FOR SHEEP AND GOATS (MILK PRODUCTION UNKNOWN

$$NE_1 = \left[\frac{\left(5 \bullet WG_{wean}\right)}{365} \right] \bullet EV_{milk}$$

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}. Default values of 4.6 MJ kg^{-1} (AFRC 1993; AFRC 1995) and 3 MJ kg^{-1} (AFRC 1998) can be used for sheep and goats, respectively.

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., Bamualim & Kartiarso 1985; Ibrahim 1985; Lawrence 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: (NEwool) is the average daily net energy required for sheep to produce a year of wool. The NEwool is calculated as follows:

EQUATION 10.12
NET ENERGY TO PRODUCE WOOL (FOR SHEEP AND GOATS)

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

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} can be used for sheep estimate. For goats this energy value is not considered unless fibre-producing goat numbers are relevant for a country (AFRC 1995).

For fibre-producing sheep NE_{wool} can be estimated that 0.25 MJ/day is retained in the fibre (AFRC 1993; AFRC 1995). For fibre-producing goats 0.25 and 0.08 MJ/day for angora and cashmere breeds (AFRC 1993; AFRC 1995), respectively.

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

Net energy for pregnancy: (NEp) 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 NEm. For sheep, the NEp 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 NEp 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 AND GOATS)

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

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 NEP IN EQUATION 10.13	
Animal category	$C_{pregnancy}$
Cattle and Buffalo	0.10
Sheep/Goats	
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); AFRC (1995), taking into account the inefficiency of energy conversion.	

When using NE_p to calculate GE for cattle, sheep and goats, 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/goats, the portion of ewes/does 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/kids 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/kids born in a year divided by the number of ewes/does 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, sheep and goats, the ratio of net energy available in a diet for maintenance to digestible energy (REM) is estimated using the following equation (Gibbs & Johnson 1993):

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

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

Where:

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

DC = digestibility of feed expressed as a fraction of gross energy (digestible energy/gross energy)

***Ratio of net energy available for growth in a diet to digestible energy consumed (REG)*:** For cattle, buffalo, sheep and goats 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 & Johnson 1993):

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

$$REG = \left[1.164 - \left(5.16 \bullet 10^{-3} \bullet DC \right) + \left(1.308 \bullet 10^{-5} \bullet (DC)^2 \right) - \left(\frac{37.4}{DC} \right) \right]$$

Where:

REG = ratio of net energy available for growth in a diet to digestible energy consumed

DC = digestibility of feed expressed as a fraction of gross energy (digestible energy/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, SHEEP AND GOATS

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

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 (Equation 10.14)

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

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

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

DC = digestibility of feed expressed as a fraction of gross energy (digestible energy/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_{mf}) and digestiblity values (DC): It is also possible to predict dry matter intake for mature and growing cattle based on body weight of the animal, either the net energy of maintenance concentration of the feed NE_{mf} (MJ kg^{-1} DM) (National Academies of Sciences & Medicine 2016) or DC, and if lactating dairy cow, fat corrected milk production. 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 10.9. These figures can also be used to estimate NE_{mf} values for mixed diets based on estimate of diet quality. For example, a mixed forage-grain diet could be assumed to have a NE_{mf} value similar to that of a high-quality forage diet. A mixed grain-straw diet could be assumed to have a NE_{mf} 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_{mf} values that are more representative of locally fed diets.

Dry matter intake for calves is estimated using the following equation:

EQUATION 10.17
ESTIMATION OF DRY MATTER INTAKE FOR CALVES

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.0582 \bullet NE_{mf} - 0.00266 \bullet NE_{mf}^{\ 2} - 0.1128\right)}{0.239 \bullet NE_{mf}} \right]$$

Where:

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

BW = live body weight, kg

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

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

EQUATION 10.18A
ESTIMATION OF DRY MATTER INTAKE FOR GROWING CATTLE

$$DMI = BW^{0.75} \bullet \left[\frac{\left(0.0582 \bullet NE_{mf} - 0.00266 \bullet NE_{mf}^{\ 2} - 0.0869\right)}{0.239 \bullet NE_{mf}} \right]$$

Where:

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

BW = live body weight, kg

NE_{mf} = estimated dietary net energy concentration of the feed or diet with default values in Table 10.9, MJ kg^{-1} DM^{-1}

Dry matter intake for feedlot cattle (on high grain diets) is estimated using the following equation:

EQUATION 10.18B
ESTIMATION OF DRY MATTER INTAKE FOR STEERS AND BULLS

$$DMI = 3.83 + 0.0143 \bullet BW \bullet 0.96$$

ESTIMATION OF DRY MATTER INTAKE FOR HEIFERS

$$DMI = 3.184 + 0.01536 \bullet BW \bullet 0.96$$

Where:

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

BW = live body weight, kg

For mature beef cows use the following values (National Academies of Sciences & Medicine 2016)

TABLE 10.8A
DMI REQUIRED BY MATURE NON DAIRY COWS BASED ON FORAGE QUALITY

Forage type	Digestibility (DC, %)	Forage DMI Capacity (kg/day), % of BW (kg)	
		Non-lactating	Lactating
Low quality	<52	1.8	2.2
Average quality	52-59	2.2	2.5
High quality	>59	2.5	2.7

For lactating dairy cows the following equation can be used (Cornell Net Carbohydrate and Protein System (CNCPS, Fox *et al.* 1992) as modified by Arnerdal (2005)

EQUATION 10.18C
ESTIMATION OF DRY MATTER INTAKE FOR LACTATING DAIRY COWS

$$DMI = 0.0185 \bullet BW + 0.305 \bullet FCM$$

Where:

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

BW = live body weight, kg

FCM = Fat corrected milk kg day^{-1} 3.5% [(0.4324 × kg of milk) + (16.216 x kg of fat)].

Equations 10.17, 10.18a, 10.18b and 10.18c 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, diet quality (NE_{mf} or DC%) and milk production. 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 and up to 4% for high yielding lactating dairy cattle.

TABLE 10.8B
EXAMPLES OF NEMF CONTENT OF TYPICAL DIETS FED TO CATTLE FOR ESTIMATION OF DRY MATTER INTAKE IN EQUATIONS 10.17 AND 10.18A

Diet type	NE_{mf} (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 DC%

10.2.3 Uncertainty assessment

This section is not being refined

10.2.4 Characterisation for livestock without species: Specific emission estimation methods

THIS SECTION IS NOT BEING REFINED

10.3 METHANE EMISSIONS FROM ENTERIC FERMENTATION

This section contains updated and elaborated guidance

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which organic matter is broken down by micro-organisms into simple molecules for their own biosynthesis and for the generation of energy by the fermentation of these simple molecules into end-products, including methane gas. The amount of methane 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 known as the rumen, located at the fore-part of their digestive tract. The rumen supports intensive microbial fermentation of the diet, which yields several nutritional advantages including the capacity to digest cellulose (the major component of fiber). 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, methane production is also 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).

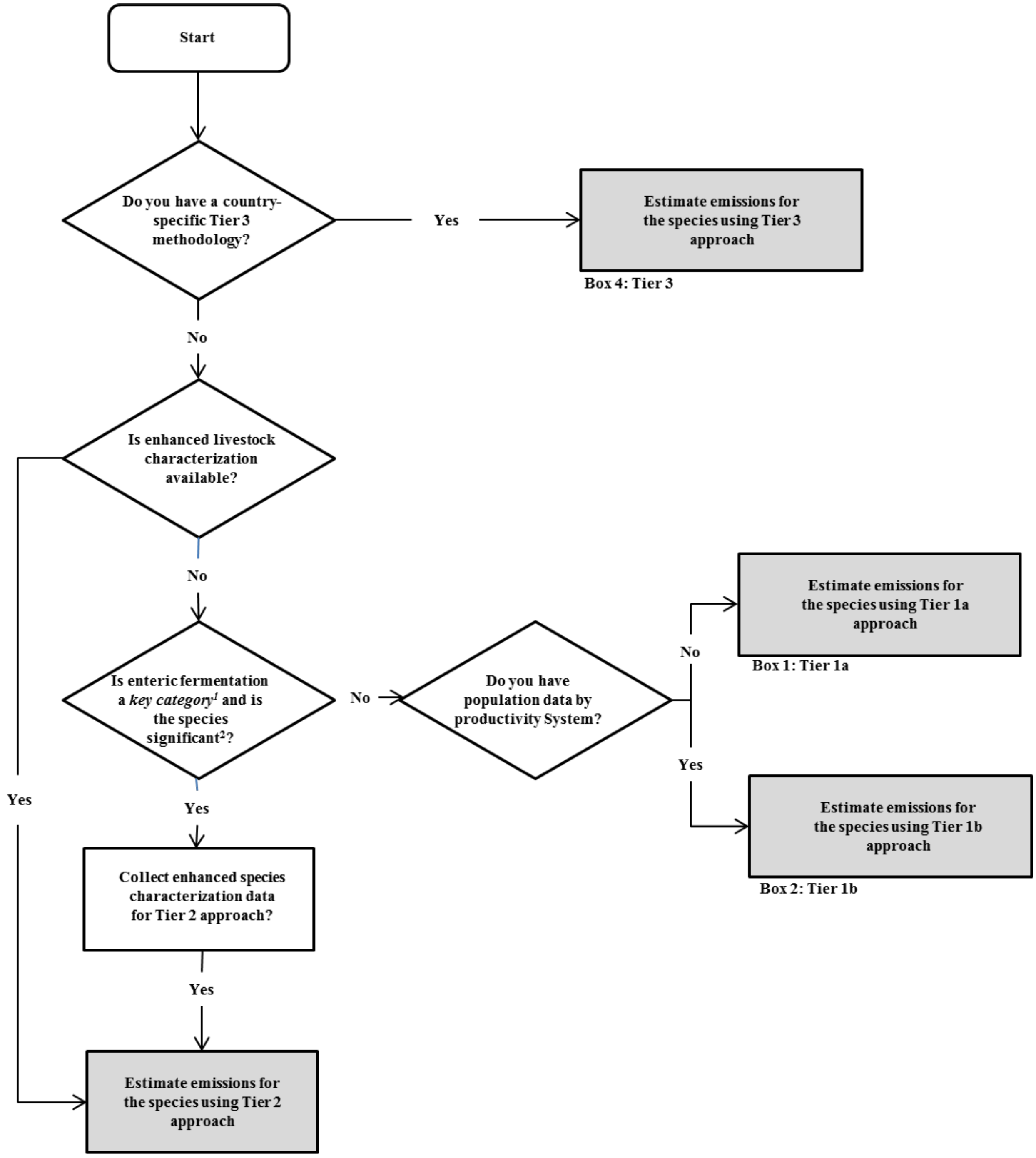
To reflect the variation in emission rates among animal species, the population of animals should be divided into subgroups, and an emission rate per animal is estimated for each subgroup. Types of population subgroups are provided in Section 10.2 (Livestock and Feed Characterisation). The amount of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

949 **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

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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 1a

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 1b

An intermediary approach, applicable in particular to countries that simultaneously have highly differentiated production systems with coexistence of low and high productivity systems, or whose agricultural production systems are transitioning from low to high productivity. Countries can consider the split in their production systems, yet still use default emission factors, to customize their emission estimates based on splits between populations of high and low productivity animals.

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 and productivity system

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 and by productivity system for ease of use.

The data used to estimate the default emission factors for enteric fermentation are presented in Annex 10A.1a and Table 10A.1b 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/Tier 2
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 low and high productivity systems and it is important to consider that these conditions may exist within individual countries. The differences in the emission factors are driven by differences in feed intake and feed characteristic assumptions (see Annex 10A.1). Table 10.11A and Table 10.11B present the enteric fermentation emission factors for cattle and buffaloes, accordingly. A range of emission factors is shown for typical regional conditions.

While the default emission factors shown in Table 10.11A 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, Western Europe and several countries of Latin America.

Animal size and population structure and production systems implemented 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.

For countries with highly differentiated agricultural systems in which there is a coexistence of very low and high productivity systems or whose agricultural systems are transitioning from local low input productivity systems to higher productivity systems and do not have the information necessary for implementing Tier 2 systems, the use of the diversification of emission factors given for an animal category provides an alternative or intermediary option. This approach can reflect changes in activity data and productivity with time, whereas the Tier 1a approach only take into account changes in the number of animals in a country.

To select emission factors from Tables 10.10, 10.11A and 10.11B 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	High Productivity Systems	Low Productivity Systems	Liveweight
Sheep	9	5	65 kg - high productivity systems; 45 kg - low productivity systems;
Swine	1.5	1	48 kg - high productivity systems; 28 kg - low productivity systems;
Horses	18	11	377 kg - high productivity systems; 238 kg - low productivity systems;
Goats	9	5	50 kg - high productivity systems; 28 kg- low productivity systems;
Camels	46	46	570 kg

Mules and Asses	10	10	245 kg
Deer	20	20	120 kg
Poultry	Not developed		
Llamas and Alpacas	8	8	65 kg
Other (e.g., bison)	To be determined[1]		
All estimates have an uncertainty of ±30-50%.			
Sources: Emission factors 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). Sources and assumptions to calculate goats EFs are detailed in Annex 10B.2.			

[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 the animals and compilers should not base their decision of an emission factor entirely on regional characteristics.

[2] The enteric fermentation emission factor shall be applied for the whole livestock population including non-mature animals.

Step 3: Total emission

To estimate total emission, the selected emission factors are multiplied by the associated animal population (Equation 10.21, Equation 10.22) and summed (Equation 10.23):

EQUATION 10.19A (TIER 1A)
ENTERIC FERMENTATION EMISSIONS FROM A LIVESTOCK CATEGORY

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

Where:

Emissions (E_T) = 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} (Table 10.11A)

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

T = species/category of livestock

EQUATION 10.19B (TIER 1B)
ENTERIC FERMENTATION EMISSIONS FROM A LIVESTOCK CATEGORY

$$E_T = \sum_{(P)} EF_{(T,P)} \bullet \left(\frac{N_{T,P}}{10^6} \right)$$

Where:

E_T = methane emissions from Enteric Fermentation in animal category T, Gg CH_4 yr^{-1}

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

$N_{(T,P)}$ = the number of head of livestock species / category T in the country classified as productivity system P.

T = species/category of livestock

P = productivity system, either high or low productivity (Table 10.11B)

EQUATION 10.20 (TIER 1)
TOTAL EMISSIONS FROM LIVESTOCK ENTERIC FERMENTATION

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

Where:

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

E_i = is the emissions for the i^{th} livestock categories and subcategories based on production system

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

Regional characteristics [6]	Animal category	Tier 1a Emission Factor [2,3] (kg CH_4 head^{-1} yr^{-1})	Comments
North America			
Cattle husbandry: 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. There are no buffalo herds, but American bison may be raised.	**Dairy Cattle**	135	Average milk production of 10,250 kg head^{-1} yr^{-1}.
	Other cattle	63	Includes mature males, mature females, calves, growing steers/heifers, and feedlot cattle.
Western Europe			
Cattle husbandry: 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 Cattle**	115	Average milk production of 7,000 kg head^{-1} yr^{-1}.
	Other cattle	53	Includes mature males, calves, and growing steers/heifers.
Buffalo husbandry: Buffalo farming system is exclusively intensive. The concentrates are largely used only during the lactation phase. Animals are maintained in paddocks, grazing practices are not widespread.	**Buffalo**	82	Includes mature females, mature males, growing animals and calves.
Eastern Europe			
Cattle husbandry: Commercialised dairy sector feeding based on forages and gains. Separate beef cow herd, primarily grazing. Minor amount of feedlot feeding with grains.	**Dairy cattle**	90	Average milk production of 3,300 kg head^{-1} yr^{-1}.
	Other cattle	58	Includes mature males, mature females, growing and replacement animals, and calves.
Buffalo husbandry: Commercialized buffalo sector feeding primarily with roughages. Buffaloes are managed according to their categories. Animals are maintained paddock and tied up during the winter, in summer they are allowed to graze	**Buffalo**	67	Includes mature females, mature males, growing animals and calves.
Oceania[4]			
Cattle husbandry: Commercialised dairy sector based on grazing. Separate beef cow herd, primarily grazing rangelands[5] and hill country of widely varying quality. Growing amount of feedlot feeding with grains. Dairy cows are a small part of the population. No Buffalo herd.	**Dairy cattle**	93	Average milk production of 4,400 kg head^{-1} yr^{-1}.
	Other cattle	63	Includes mature males, mature females and young.
Latin America			

Cattle husbandry: 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 Cattle**	87	Average milk production of 2,050 kg head^{-1} yr^{-1}
	Other cattle	56	Includes mature females, mature males, growing steers/heifers and calves.
*Buffalo husbandry:*Buffalo husbandry is based on extensive systems in native or cultivated pastures in lowlands and uplands, most often without supply of concentrated feed. Milk production is based on pasture with frequent supplementation of roughage (sugar cane, silage, etc.), with a predominance of one single milking.	**Buffalo**	77	Includes mature females, mature males, growing animals and calves.
Asia			
Cattle husbandry: Commercialised dairy sector is experienced fundamental changes due to increasing number of large farms with intensive production system based on grains and forage. Cattle kept in traditional production systems are multi-purpose, providing draft power and some milk within farming regions. Cattle of all types are smaller than those found in most other regions.	**Dairy cattle**	78	Average milk production of 3,200 kg head^{-1} yr^{-1}
	Other cattle	54	Includes mature males, mature females, growing and replacement animals, and calves.
Buffalo husbandry: Buffaloes are generally swamp type. Buffaloes are raised by smallholder farmers as source of draft power. Animals are commonly grazed in field and fed on agriculture residual products. Milk yield per cow is low. Nevertheless, the dairy buffalo breeding is rapidly developing in countryside of Asia.	**Buffalo**	76	Includes breeding and working bulls, growing animals and calves
Africa			
Cattle husbandry: 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 cattle**	66	Average milk production of 1,300 kg head^{-1} yr^{-1}
	Other cattle	50	Includes mature males, mature females, growing and replacement animals, and calves.
Buffalo husbandry: Small-scale buffalo sector well-integrated with cropland. Animals are raised for multi-purpose. Feeding primarily depends on roughages and crop-residues. Minor commercial dairy buffalo farms feeding with concentrate feed mixture.	**Buffalo**	82	Includes breeding and working bulls, growing animals and calves
Middle East			

Cattle husbandry: Majority of cattle population is still kept by small holders in the traditional production systems. The animals are fed primarily by crop residues and are grazed. Most animals are dual-purpose. In contrast to the small-scale farms, commercial dairy sector is generally intensive, mainly based on compound feed and grains.	**Dairy cattle**	78	Average milk production of 2,500 kg head^{-1} yr^{-1}
	Other cattle	56	Includes mature males, mature females, growing and replacement animals, and calves.
*Buffalo husbandry:*Buffalo farming system primarily based on smallholders rearing animals for meat, milk and draught. Animals obtain their feeding by grazing. Minor commercialized buffalo sector feeding forage and concentrate supplemented feed.	**Buffalo**	63	Includes breeding and working bulls, growing animals and calves
Indian Subcontinent			
Cattle husbandry: 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. Cattle in this region are the smallest compared to cattle found in all other regions.	**Dairy cattle**	76	Average milk production of 2,000 kg head^{-1} yr^{-1}
	Other Cattle	47	Includes mature males, mature females, growing and replacement animals, and calves.
*Buffalo husbandry:*Smallholder buffalo sector feeding poor quality roughages and crop-residues. Buffaloes are primarily free grazing. Concentrates are fed to dairy animals during last months of pregnancy. Dairy and meat production are intimately related. Animals are used as draft power. Minor commercialized buffalo sector providing animals with balanced ration.	**Buffalo**	85	Includes breeding and working bulls, growing animals and calves

[1] Emission factors should be derived on the basis of the characteristics of the cattle and feed of the animals and compilers should not base their decision of an emission factor entirely on rregional characteristics.

[2] The values represent averages within region. Existing values were derived using Tier 2 method and the data in Tables 10A.1-1–10A.1-5. Data on a livestock population mix corresponding to low and high productivity systems were used.

[3] Uncertainty values from the previous guidelines were validated during the development of the 2019 emission factors using a Monte Carlo analysis, based on data compiled during the emission factor development process. It is recommended to continue to use Tier 1 emission factor uncertainty ranges as defined in Section 10.3.4 of the IPCC 2006 Guidelines.

[4] All data are weighted values, representative of Australia and New Zealand. For Pacific Island nations, refer to Asia values.

[5] Rangelands are defined as land primarily covered by woodlands, shrublands, grasslands and savannas, as well as introduced plant species that are naturalised (Grice *et al.* 2008).

[6] Sources: Cattle husbandry of Asia: IPCC (2006); Ma *et al.* (2007); Ma *et al.* (2012); FAO *et al.* (2014) . Cattle husbandry of Middle East: Kamalzadeh *et al.* (2008); Karakok (2007); Yilmaz *et al.* (2012); Yilmaz and Wilson (2012); FAO *et al.* (2014). Buffalo husbandry of Western Europe: Borghese (2013); Neglia *et al.* (2014); Sabia *et al.* (2015). Buffalo husbandry of Eastern Europe: FAO (2005). Buffalo husbandry of Latin America: Bernardes (2007). Buffalo husbandry of Asia: Cruz (2007); Yang *et al.* (2007). Buffalo husbandry of Africa: Habeeb *et al.* (2016); Radwan (2016); Ali *et al.* (2009); Hassan and Abdel-Raheem (2013); Ibrahim (2012); Soliman (2009). Ali *et al.* (2009). Buffalo husbandry of Middle East: Azary *et al.* (2007); Soysal (2013); Dezfuli *et al.* (2011); Hossein-zadeh *et al.* (2012); Soysal *et al.* (2007); Naserian and Saremi (2007); Ermetin (2017). Dezfuli *et al.* (2011). Buffalo husbandry of Indian subcontinent: Ranjhan (2007); Anjum *et al.* (2012); Khan *et al.* (2008); Khadda *et al.* (2017); Ahirwar (2010); Khan *et al.* (2007); Chawla *et al.* (2009).

TABLE 10.11B[5] ENTERIC FERMENTATION EMISSION FACTORS FOR CATTLE1 (TIER 1B)			
Region Cattle category	**Productivity System**	**Emission Factor [2,3] ($kg\ CH_4\ head^{-1}\ yr^{-1}$)**	**Comments**
Latin America			
Dairy Cattle	High Productivity Systems	103	Average milk production of 3,400 kg $head^{-1}\ yr^{-1}$
	Low Productivity Systems	78	Average milk production of 1,250 kg $head^{-1}\ yr^{-1}$
Other Cattle	High Productivity Systems	60	Includes mature males, multi-purpose mature females, growing and replacement animals, and calves.
	Low Productivity Systems	55	
Asia[4]			
Dairy Cattle	High Productivity Systems	96	Average milk production of 5,000 kg $head^{-1}\ yr^{-1}$
	Low Productivity Systems	71	Average milk production of 2,600 kg $head^{-1}\ yr^{-1}$
Other Cattle	High Productivity Systems	43	Includes mature males, multi-purpose mature females, growing and replacement animals, and calves.
	Low Productivity Systems	55	
Africa[6]			
Dairy Cattle	High Productivity Systems	77	Average milk production of 2,200 kg $head^{-1}\ yr^{-1}$
	Low Productivity Systems	62	Average milk production of 500 kg $head^{-1}\ yr^{-1}$
Other Cattle	High Productivity Systems	60	Includes mature males, multi-purpose mature females, growing and replacement animals, and calves.
	Low Productivity Systems	46	
Middle East[6]			
Dairy Cattle	High Productivity Systems	94	Average milk production of 3,900 kg $head^{-1}\ yr^{-1}$
	Low Productivity Systems	62	Average milk production of 1,300 kg $head^{-1}\ yr^{-1}$
Other Cattle	High Productivity Systems	57	Includes mature males, multi-purpose mature females, growing and replacement animals, and calves.
	Low Productivity Systems	52	
Indian subcontinent			
Dairy Cattle	High Productivity Systems	75	Average milk production of 3,000 kg $head^{-1}\ yr^{-1}$
	Low Productivity Systems	74	Average milk production of 1,700 kg $head^{-1}\ yr^{-1}$
Other Cattle	High Productivity Systems	43	Includes mature males, multi-purpose mature females, growing and replacement animals, and calves.
	Low Productivity Systems	47	

[1] Emission factors should be derived on the basis of the characteristics of the cattle and feed of the animals and compilers should not base their decision of an emission factor entirely on rregional characteristics.

[2] The values represent averages within region. Existing values were derived using Tier 2 method and the data in Tables 10A.1-1–10A.1-4.

[3] Uncertainty values from the previous guidelines were validated during the development of the 2019 emission factors using a Monte Carlo analysis, based on data compiled during the emission factor development process. It is recommended to continue to use Tier 1 emission factor uncertainty ranges as defined in Section 10.3.4 of the *IPCC 2006 Guidelines.*

[4] Island nations from Oceania may wish to use a Tier 1b approach. In this case, they could used values from Asia, or low productivity systems from Asia and high the Tier 1a Emission Factor from Oceania, whichever is nearer to their production systems.

[5] Tier 1b emission factors were not derived for Europe or North America as the range in production systems was not seen to be large enough to merit specific emission factors, and most countries from these regions have developed Tier 2 systems that encompass the variability of their management systems.

[6] North African countries may wish to use values derived for the Middle East if productions systems are more similar

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 and that rate of conversion is embodied in the methane conversion factor (Ym), defined as the percentage of gross energy intake converted to methane. 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.

TABLE 10.12[5]
CATTLE/BUFFALO METHANE CONVERSION FACTORS (Y_M)

Livestock category	Description	Digestibility (%)	EF_DMI, g CH_4 kg DMI^{-1}	Y_m[3]
[1,4]Dairy Cows (Cattle and Buffalo)	High-producing cows (>8500 kg/head/yr^{-1})	DC ⩾ 70	19.0	5.7
	Medium producing cows (5000 – 8500 kg yr^{-1})	DC 62-70	21.0	6.3
	Low producing cows (<5000 kg yr^{-1})	DC < 62	21.4	6.5
[2]Non dairy and multi-purpose cattle	> 75 % forage	DC ≤ 62	23.3	7.0
	Rations of >75% high quality forage and mixed rations, forage of between 15 and 75% the total ration mixed with grain, and/or silage.	DC > 62–71	21.0	6.3
	Feedlot (all other grains, 0-15% forage)	DC > 72	11.5	3.5
	Feedlot (corn grain, distillers grains, 0-15% forage)	> 72	10.0	3.0

1Appuhamy *et al.* (2016); Jayasundara *et al.* (2016) and Niu *et al.* (2018)

[2] Sources: Boadi and Wittenberg (2002); Pinares-Patiño *et al.* (2003); Boadi *et al.* (2004); Beauchemin and McGinn (2005); Beauchemin and McGinn (2006a); Beauchemin and McGinn (2006b); Chaves *et al.* (2006); Jordan *et al.* (2006a);

Jordan *et al.* (2006b); Beauchemin *et al.* (2007); Hegarty *et al.* (2007); Hart *et al.* (2009); McGinn *et al.* (2009); Mc Geough *et al.* (2010a); Mc Geough *et al.* (2010b); Doreau *et al.* (2011); Hales *et al.* (2012); Kennedy and Charmley (2012); Staerfl *et al.* (2012); Chung *et al.* (2013); Hünerberg *et al.* (2013); Fiorentini *et al.* (2014); Hales *et al.* (2014); Hales *et al.* (2015); Troy *et al.* (2015); Nascimento *et al.* (2016); Vyas *et al.* (2016a); Vyas *et al.* (2016b); Baron *et al.* (2017); Hales *et al.* (2017).

[3] Uncertainty values are ± 20% based on published standard deviations from Niu et al. (2018) and data compilations for dairy cattle as described in Annex B.4.

[4] Ym cited for Dairy cattle are for lactating dairy cows. For cattle during their dry phase, in high and medium production systems, the non dairy high quality forage value (6.3) should be selected and for low production systems the value for >75% low quality forage (7) should be selected.

[5] For details on the development of these values, refer to Annex 10B.4

It is important to consider 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. Though there is important variability in the results of scientific studies that relate feed quality to emissions, numerous empirical and biochemical modelling studies demonstrate both statistical significance and the biochemical processes that impact methane production with the introduction of concentrates to ruminant diets (Mills *et al.* 2001; Mills *et al.* 2003; Ellis *et al.* 2006; Ellis *et al.* 2007; Ellis *et al.* 2009; Ellis *et al.* 2010; Alemu *et al.* 2011; Bannink *et al.* 2011; Ellis *et al.* 2014; Escobar-Bahamondes *et al.* 2016; Kebreab *et al.* 2016).

The Ym of dairy cows is dependant on annual milk production levels, as it relates to feed quantity and quality. The lower Ym of the very high producing dairy cattle may be a result of the reduced digestibility resulting from high rates of passage of feed materials. Non feedlot diets can be differentiated between dominantly unimproved forage based diets and mixed concentrate diets or high quality forage diets. Emissions from feedlot animals are influenced by the type of grain fed to the animals during the finishing stage. A CH_4 conversion factor of zero is assumed for all juveniles consuming only milk (i.e., milk-fed lambs and calves).

Nonetheless, there are important interactions between breeds, regions and feed quality resulting in a variable impact of feed and forage quality on Y_m (Cottle & Eckard 2018). Detailed studes from specific regions with specific breeds and feeds may provide alternative interpretions of the role of variability in feed quality in impacting methane conversion rates (Charmley *et al.* 2016). Considering interactions between feed quality and breed, it is *good practice* for parties to derive their own Ym values considering their herd structure and their typical range of feed quality and feed characteristics.

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 low quality forages particularly in tropical regions as the available data are sparse. However, in a study by Kennedy and Charmley (2012) the Y_m values for tropical grasses and legumes were within the ranges described in Table 10.12.

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 and head enclosures for housing individual animals (Johnson & 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). Hammond *et al.* (2015) present an in-depth review of the advantages and limitations of methane measurement techniques used to determine Y_m values.

Table 10.13 proposes a common Y_m value for all sheep irrespective of feed quality values. This value is based on the mean value of raw data from New Zealand collated between 2009 and 2015 (Swainson *et al.* 2016). Data were derived from respiration chamber measurements where intake was accurately measured and covered a range of diet qualities. These replace values in the 2006 guidelines which were based on indirect measurements using the sulphur hexafluoride tracer technique where dry matter intake was generally estimated in grazing animals (Ulyatt *et al.* 2002a; Ulyatt *et al.* 2002b; Ulyatt *et al.* 2005). The mean value of 6.7% is most appropriate for situations where average dry matter intake per day is between 0.6 and 0.8 kg/day with a value of 7.0% being more appropriate where average intake is <0.6kg/day, and a value of 6.5% being more appropriate where average intakes are >0.8kg/day.

TABLE 10.13
SHEEP AND GOATS CH_4 CONVERSION FACTORS (Y_M)

Category	Y_m [1]
Sheep	6.7% ± 0.9
Goats	5.5% ± 1.0%

Sources and assumptions to calculate goats Ym are detailed in Annex 10B.2.
[1] The ± values are the the standard deviation of the mean of the Y_m..

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

Using the energy balance Tier 2 approach an emission factor for each animal category should be developed following Equation 10.24:

EQUATION 10.21A
METHANE 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

In cases in which the inventory compiler has used the simplified Tier 2 the emission factors should be calculated following equation 10.25:

EQUATION 10.21B
METHANE EMISSION FACTORS FOR ENTERIC FERMENTATION FROM A LIVESTOCK CATEGORY

$$EF = DMI \bullet 365 \bullet \left(\frac{\text{EF\_DMI}}{1000} \right)$$

Where:

EF = emission factor, kg CH_4 head^{-1} yr^{-1}

DMI = kg DMI day^{-1}

EF_DMI = CH_4 rate emissions, kg CH_4 kg DMI^{-1} (Table 10.12)

365= days per year

1000 = conversion from g CH_4 to kg CH_4

These emission factor equations assume 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 with 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 may include:

- depression in digestibility with increasing levels of consumption or due to rumen acidification, feed preparation or diet composition putting limits to feed intake;
- breed or genotype variation in maintenance requirement; and
- heat and cold stress effects on feed intake and maintenance requirements.
- Likewise, a host of interacting factors cause variation in the rumen microbiome and its fermentation profile, and hence in hydrogen production which delivers the main substrate for methanogens. These factors lead to variation in Y_m that is not included in Tier 2 methodology and may include:
- variation in feed digestibility (DC);
- level of feed intake chemical composition of feed;

- kinetics of particle and fluid passage and of digestion, rumen volume, rumen fermentation profile; and
- other factors (such as secondary plant compounds, additives and other products) affecting the rumen microbiome.

Accurate estimation of diet DC is singularly important in the estimation of feed intake and enteric methane emission, as previously emphasized. A 10% error in DC will result in errors in CH_4 emissions ranging from 12 to 20% depending on the dietary circumstances for which calculations are made. The depression in DC with increasing daily amounts of feed consumed (increasing rates of passage) is not inherently considered with Tier 2 and this neglect could underestimate feed intakes of high producing dairy cows consuming mixtures of concentrates and forages as is common in the North America and Europe, and hence underestimate methane emission. However, accounting for the reduction of Y_m with increased feed intake may compensate this underestimation. The balance between both effects (i.e. a reduction of feed digestibility and of Y_m) determines the net effect on methane emission which may vary with dietary circumstances. More complex models may be developed as Tier 3 to capture the intricacies of such effects.

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 (Bannink *et al.* 2011; Gregorini *et al.* 2013; Huhtanen *et al.* 2015; Dougherty *et al.* 2017). The Netherlands employ Tier 3 approach using a mechanistic model (Bannink *et al.* 2011) to estimate CH_4 yield from dairy cattle while the US use mechanistic models (Baldwin 1995; Kebreab *et al.* 2008) to refine estimates of Ym for dairy and beef in different states within the US.

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 the strongest indicator of CH_4 yield, the CH_4 per digested fiber is not constant and enteric fermentation of similar fibrous feeds can result in different Y_m values. For example, grass silage made from grass cut at different stages of maturity resulted in strongly different carbohydrate and protein composition, resulting in Y_m values varying from 5.5 to 6.9% with increased maturity and intake (Warner *et al.* 2017). Exchange of carbohydrates may also lead to a lower Y_m as demonstrated in studies where an increased dietary starch content through a higher proportion of corn silage (Hassanat *et al.* 2013; Benchaar *et al.* 2014) or through a higher proportion of starch containing concentrates (Aguerre *et al.* 2011). Prerequisite for the use of more complex prediction models for broad country inventories is that the data need to be provided to drive these more complex models of feed intake or Y_m. It is often difficult to define animal characteristics, productivity, and DC accurately for a livestock category in various regions or various production systems in a country. Of particular importance is a good characterization of roughages when they constitute a main part of the diet.

Ongoing global research on mitigation strategies currently, such as the use of direct methanogen inhibitors, oxygen-rich anions, fats and oils, ionophores or condensed tannins, 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 in agricultural practice, and apply it only to emissions by those livestock where take-up can be validated. Mitigation measures and their representation in inventory compilation should be supported by peer-reviewed publications.

Concluding, approaches to improve estimates of feed intake (i.e. of diet composition, DC and dietary GE content) and Ym, and approaches to account for specific mitigation measures are to be encouraged, given due care on limitations of the scope and on production circumstances where mitigation measures are applied and to which predictive models or relationships must apply as well.

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 10.11, 10.12, 10.13) 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

NO CHANGES TO THIS SECTION

Activity data

NO CHANGES TO THIS SECTION

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

No changes to this section

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. In the 2019 IPCC refinement, a new approach of Tier 1 based per unit VS emission factors, updated Tier 2 based per unit VS and parameters for different manure management systems, and revised equation on how to deal with non-CO_2 emissions due to biogas production which consider fugitive emissions, digestate storage and housing emissions were developed.

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 as shown in 2006 IPCC guideline.

To be consistent with consideration of differing productivity classes in section of enteric fermentation, a new tier 1 was developed. In regions, particularly in developing countries production systems can vary between high productivity systems aimed at commercial food production and low productivity systems, largely serving local food production. In this case countries may choose to use a Tier 1 method in which emission factors are defined for low and high productivity systems based on the updated volatile solids and B_0, and the values of volatile solids was aligned with updated enteric fermentation section.

Guidance for determining which methods to use is shown in Figure 10.3 decision tree.

Tier 1A and Tier 1B

A simplified method that requires livestock population data by animal species/category and climate region or temperature, in combination with IPCC default emission factors per unit of volatile solid, default volatile solid data, and country-specific manure management system data to estimate emissions. Manure management system data have been collected for regions and countries by the FAO and are presented in Annex 10A.2-2 to Table 10A.2-7. Because some emissions from manure management systems are highly temperature dependent, it is *good practice* to consider the climate zone associated with the locations where manure is managed.

As was the case with enteric fermentation the Tier 1B applies to countries with highly differentiated agricultural systems in which there is a coexistence of very low and high productivity systems or whose agricultural systems are transitioning from local low input productivity systems to higher productivity systems. In this case, where countries do not have the information necessary for implementing Tier 2 systems, the use of the diversification of emission factors given for an animal category provides an alternative or intermediary option, referred to as a Tier 1B option. The Tier 1B approach will provide some estimate of the changes in both productivity and manure management that occur when a transition from lower productivity systems to higher productivity systems occurs.

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 Characterization (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 unit VS per year.

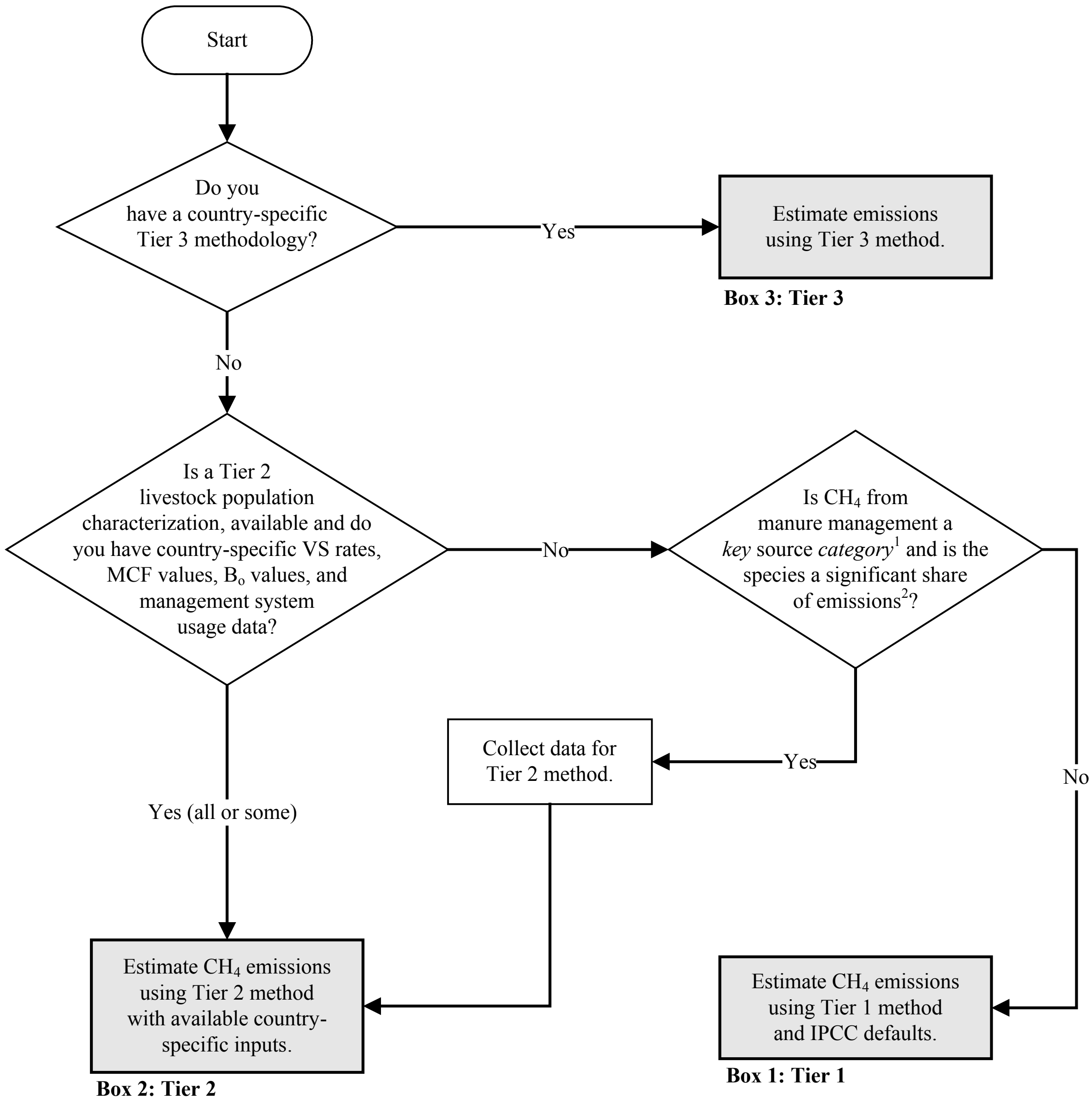
- Tier 1A and 1B: Identify default values (Table10.14A- Table 10.14E, Table 15) on Emission Factors for each livestock subcategory in terms of kilograms of methane per unit VS per year.
- Tier 2: Collect or identify default values (Table10 A.2-2- Table 10A.2-7) of information on the proportion of manure that is managed in different types of manure management and storage facilities, then multiply local manure management specific methane conversion factors (Table 10.17) for different climate zones and the animal category specific maximum methane producing capacity to develop emission factor based on per unit of VS.

Step 3: Calculate methane emission for each livestock subcategory

- Tier 1: Identify default values (Table10A.2-2- Table 10A.2-7) on the proportion of different manure management and storage facilities; Use default values (Table 14 and Equation 23A or Equation 23B) of the quantity of volatile solids produced by each livestock subcategory in terms of kilograms of VS per animal per day. then multiply default manure management specific methane emission factors (Table10-14A- Table 10A-14E, Table 15) by the animal category specific volatile solid excretion, proportion of manure management system, and animal populations of each categories of livestock to estimate to methane emission for animal species.
- Tier 2: Collect information on the proportion of manure that is managed in different types of manure management and storage facilities, develop country-specific estimates (Equation 25) of the quantity of volatile solids produced by each livestock subcategory in terms of kilograms of VS per animal per year, then multiply local manure management specific methane emission factors, by country-specific volatile solid excretion, proportion of manure management system, and animal populations of each categories of livestock to estimate to methane emission for animal 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.

The calculation of CH_4 emissions from manure management for Tier 1A is based on the following equation:

EQUATION 10. 22A
CH_4 EMISSIONS FROM MANURE MANAGEMENT (FOR TIER 1A)

$$CH_{4(mm)} = \left[\sum_{T,S} \left(N_{(T)} \bullet VS_{(T)} \bullet AWMS_{(T,S)} \right) \bullet EF_{(T,S)} / 1000 \right]$$

Where:

$CH_{4(mm)}$ = CH_4 emissions from Manure Management in the country, kg CH_4 yr^{-1}

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

$VS_{(T)}$ = annual average VS excretion per head of species/category *T*, kg VS $animal^{-1}$ yr^{-1} (Table 10.14 by Equation 10.23A)

$AWMS_{(T,S)}$ = fraction of total annual VS for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless, default regionally specific AWMS fractions are found in Tables 10A.2-2 through 10A.2-7 in Annex A.2

$EF_{(T,S)}$ = emission factor for direct CH_4 emissions from manure management system *S,* by animal species/category in the country, g CH_4 kg VS^{-1} in manure management system *S* (Table 10.15 - Table 10.17)

S = manure management system

T = species/category of livestock

The calculation of CH_4 emissions from manure management for Tier 1B is based on the following equation:

EQUATION 10. 22B
CH_4 EMISSIONS FROM MANURE MANAGEMENT (FOR TIER 1B)

$$CH_{4(mm)} = \left[\sum_{T,S,P} \left(N_{(T,P)} \bullet VS_{(T,P)} \bullet AWMS_{(T,S,P)} \right) \bullet EF_{(T,S,P)} / 1000 \right]$$

Where:

$CH_{4(mm)}$ = CH_4 emissions from Manure Management in the country, kg CH_4 yr^{-1}

$N_{(T,P)}$ = number of head of livestock species/category *T* in the country, for productivity system P

$VS_{(T,P)}$ = annual average VS excretion per head of species/category *T*, for productivity system, P in kg VS $animal^{-1}$ yr^{-1} (Table 10.14A calculated by Equation 10.22D),

$AWMS_{(T,S,P)}$ = fraction of total annual VS for each livestock species/category *T* that is managed in manure management system *S* in the country, , for productivity system P; dimensionless, default regionally specific AWMS fractions are found in Tables 10A.2-2 through10A.2-7 in Annex A.2,

$EF_{(T,S,P)}$ = emission factor for direct CH_4 emissions from manure management system *S,* by animal species/category T, in manure management system *S*, for productivity system P (Table 10.14B - Table 10.15) g CH_4 kg VS^{-1}

S = manure management system

T = species/category of livestock

P= high productivity system or low productivity system

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 (A or B) :

When using the Tier 1 method, methane emission factors per unit of VS by livestock category or subcategory are used. Default emission factors by average annual temperature are presented in Table 10.15to Table 10.16 for each of the recommended population subcategories. These emission factors represent the range in manure management practices used in each region, as well as the difference in emissions due to temperature.

Tables 10A.2-2 through 10A.2-7 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.

Annual volatile solid rates should be determined for each livestock category defined by the livestock population characterization. Country-specific rates may either be taken directly from documents or reports such as agricultural industry and scientific literature, or calculated based on dry matter input (DMI), ash content and urinary energy (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 volatile solid excretion rates presented in Table 10.14 can be used. These rates are presented in units of volatile solid 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 10.22C for a Tier 1A calculation.

EQUATION 10. 22C
ANNUAL VS EXCRETION RATES

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

Where:

$VS_{(T,P)}$ = annual VS excretion for livestock category T, kg VS animal^{-1} yr^{-1}

$VS_{rate(T)}$ = default VS excretion rate, kg VS (1000 kg animal mass)$^{-1}$ day^{-1} (see Table 10.16)

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

For a Tier 1B calculation when animal populations can be divided into high and low producitivy classes, parameters are split by their productivity class and volatile solid excretion is calculated separately for these systems:, as shown in Equation 10.22D for a Tier 1B calculation.

EQUATION 10. 22D
ANNUAL VS EXCRETION RATES (TIER 1B)

$$VS_{(T,P)} = \left(VS_{rate(T,P)} \bullet \frac{TAM_{T,P}}{1000} \right) \bullet 365$$

Where:

$VS_{(T,P)}$ = annual VS excretion for livestock category *T*, for productivity system P, kg VS animal^{-1} yr^{-1}

$VS_{rate(T,P)}$ = default VS excretion rate, for productivity system P, kg VS (1000 kg animal mass)$^{-1}$ day^{-1} (see Table 10.16)

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

Default TAM values are provided in Annex 10A.1 and Annex 10A.2[4] as well as in the Annexes of Chapter 10 of the *2006 IPCC Guidelines* However, it is preferable to collect country-specific TAM values to be able to track changes in emissions with changes in productivity in certain animal 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 volatile solid excreted by their swine population.

Table 10.14B to Table 10.14E and Table 15 shows the default emission factors per kg of volatile solid excretion and year for cattle, swine for each manure management and climate zone. Emission factors are listed for the climate zone where the livestock manure is managed. The temperature data should be based on national meteorological statistics where available. It is good practice for countries to estimate the percentage of animal populations in different climate zones and compute a weighted average emission factor. Where this is not possible, an estimate should be made based on the proportion of area in each climate zone; however, this may not give an accurate estimate of emissions that are highly sensitive to temperature variations (e.g., liquid/slurry systems).

Separate emission factors are shown for high and low productivity systems in these Tables, reflecting the general differences in feed intake and feed characteristics of the animals in regions that have highly differential production systems existing in the same country. 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 paddocks and ranges, drylots, and daily spreading on fields (Woodbury & Hashimoto 1993).

[4] Further TAM values for swine and poultry will be derived from FAO GLEAM databases FAO. (2017) *Global Livestock Environmental Assessment Model v2.0. Data reference year 2010. Revision 4, June 2017*. Food and Agriculture Oganization of the United Nations. and included in the final draft

TABLE 10. 14 A
DEFAULT VALUES FOR VOLATILE SOLID EXCRETION RATE (KG VS (1000 KG ANIMAL MASS)$^{-1}$ DAY^{-1}

Category of animal	Region																		
	North America	Western Europe	Eastern Europe	Oceania[7]	Latin America			Africa[6]			Middle East[6]			Asia			India sub-continent		
					Mean	High P.[1]	Low P.[1]	Mean	High P.	Low P.	Mean	High P.	Low P.	Mean	High P.	Low P.	Mean	High P.	Low P.
Dairy cattle[4]	9.3	7.2	6.5	6.0	9.0	10.1	6.7	15.8	14.3	19.5	11.1	11.8	8.4	9.0	9.2	8.1	14.7	16.1	9.7
Other cattle[4]	7.1	5.5	7.5	5.6	11.0	10.3	11.3	11.8	12.5	10.2	14.1	16.8	10.5	9.9	10.6	6.8	12.2	12.0	13.4
Buffalo[4]	NR	10.3	10.3	NR	9.0	NE			NE		10.3	NE		10.3	NE		10.3	NE	
Swine[3]	3.5	4.3	4.0	4.0	5.3	3.4	7.3	6.3	4.4	8.3	5.7	4.0	7.4	5.7	4.4	7.1	7.1	5.6	8.7
Finishing	4.2	5.2	4.9	5.6	6.6	4.4	8.8	7.2	5.4	9.1	6.3	4.5	8.0	6.6	5.2	7.9	8.0	6.6	9.4
Breeding	1.9	2.3	2.0	2.1	3.0	1.7	4.2	4.1	2.5	5.8	3.5	2.3	4.7	3.4	2.4	4.4	4.3	3.0	5.5
Poultry[3]	14.2	13.0	12.4	15.5	15.0	13.3	16.8	12.6	12.4	12.7	15.2	13.7	16.6	14.3	10.6	18.0	15.2	14.4	16.1
Hens >/= 1 yr	9.2	9.3	9.4	8.5	12.3	9.1	15.6	9.7	8.1	11.3	12.1	8.3	15.8	12.1	8.6	15.5	12.9	11.0	14.9
Pullets	5.7	5.6	6.0	6.2	12.8	5.8	19.8	11.0	5.9	16.1	12.2	5.7	18.8	14.4	5.4	23.5	12.9	6.5	19.3
Broilers	16.7	17.4	15.8	18.3	17.2	15.4	19.1	15.5	15.9	15.0	17.7	17.2	18.2	18.9	15.2	22.6	18.1	17.6	18.6
Turkeys[5]	10.3																		
Ducks[5]	7.4																		
Sheep[5]	8.3				11.4														
Goats[5]	9.1				10.00														
Horses[5]	5.65				7.2														

Mules/ Asses[5]	7.2
Camels[5]	11.5
1. High P and Low P refer to high and low productivity required for Tier 1B methodology 2. NE is reported when values are not estimated, due to their not being adequate differences between high and low productivity production systems and NR refers to situations in which these animal categories do not occur in these regions. 3. Values are taken from FAO GLEAM databases (FAO 2017). High and low estimates are simplified extracts from the model database and may be prone to refinement in the final draft. Means of high and low productivity systems are simple means and will be refined in the final order draft. 4. Values are derived from diets used in the calculation of enteric fermentation Tier 1 emission factors. 5. Values are derived from data in Appendix 10A.2 of the *2006 IPCC Guidelines.* 6. North African Countries may wish to use values from the Middle East if their production systems are more similar. 7. Island nations from Oceania may wish to use a Tier 1B approach. In this case, they could used values from Asia, or low productivity systems from Asia and high the Tier 1A Emission Factor from Oceania, whichever is nearer to their production systems.	

TABLE 10.14B
AVERAGE REGIONAL CH_4 EMISSION FACTORS OF CATTLE BY CLIMATE ZONE (G CH_4 KG VS^{-1})

Livestock species	Productivity Class	Manure Storage System[4]	Cool				Temperate		Warm			
			Cool Temp. Moist	Cool Temp. Dry	Boreal Moist	Boreal Dry	Warm Temp. Moist	Warm Temp. Dry	Tropical	Tropical Wet	Tropical Moist	Tropical Dry
Dairy Cattle	High Productivity	Uncovered anaerobic lagoon	96.5	107.7	80.4	78.8	117.4	122.2	122.2	128.6	128.6	128.6
		Liquid/Slurry, and Pit storage below animal confinements > 1 month [5]	33.8	41.8	22.5	22.5	59.5	65.9	0.9	122.2	117.4	119.0
		Liquid/Slurry and pit storage below animal confinements < 1 month	9.6	12.9	6.4	6.4	20.9	24.1	40.2	61.1	57.9	67.5
		Deep bedding > 1 month	33.8	41.8	22.5	22.5	59.5	65.9	0.9	122.2	117.4	119.0
		Deep bedding< 1 month	4.4				10.5		28.9			
		Solid storage	3.2				6.4		8.0			
		Solid storage – Covered/compacted	3.2				6.4		8.0			
		Solid storage – Bulking agent addition	0.8				1.6		2.4			
		Solid storage – Additives	1.6				3.2		4.0			
		Dry lot	1.6				2.4		3.2			
		Daily spread	0.2				0.8		1.6			
		Composting - In-vessel[3]	0.8									
		Composting - Static pile (Forced aeration)[3]	1.6				3.2		4.0			
		Composting - Intensive windrow[3]	0.8				1.6		2.4			
		Composting – Passive windrow (Unfrequent turning)[3]	1.6				3.2		4.0			
		Pasture/Range/Paddock[1]	0.8									
		Poultry manure without or without litter	NA									
		Aerobic treatment	0.0									

		Burned for fuel	16.1									
	Low Productivity	Uncovered anaerobic lagoon	52.3	58.4	43.6	42.7	63.6	66.2	66.2	69.7	69.7	69.7
		Liquid/Slurry, and Pit storage below animal confinements > 1 month [5]	18.3	22.6	12.2	12.2	32.2	35.7	0.5	66.2	63.6	64.5
		Liquid/Slurry and pit storage below animal confinements < 1 month	5.2	7.0	3.5	3.5	11.3	13.1	21.8	33.1	31.4	36.6
		Deep bedding > 1 month	18.3	22.6	12.2	12.2	32.2	35.7	0.5	66.2	63.6	64.5
		Deep bedding< 1 month	2.4				5.7		15.7			
		Solid storage	1.7				3.5		4.4			
		Solid storage – Covered/compacted	1.7				3.5		4.4			
		Solid storage – Bulking agent addition	0.4				0.9		1.3			
		Solid storage – Additives	0.9				1.7		2.2			
		Dry lot	0.9				1.3		1.7			
		Daily spread	0.1				0.4		0.9			
		Composting - In-vessel[3]	0.44									
		Composting - Static pile (Forced aeration)[b]	0.9				1.7		2.2			
		Composting - Intensive windrow[3]	0.4				0.9		1.3			
		Composting – Passive windrow (Unfrequent turning)[3]	0.9				1.7		2.2			
		Pasture/Range/Paddock[1]	0..4									
		Poultry manure without or without litter	NA									
		Aerobic treatment	0.0									
		Burned for fuel	8.7									
Non Dairy Cattle	High Productivity	Uncovered anaerobic lagoon	72.4	80.8	60.3	59.1	88.0	91.7	91.7	96.5	96.5	96.5
		Liquid/Slurry, and Pit storage below animal confinements > 1 month [3]	25.3	31.4	16.9	16.9	44.6	49.4	0.7	91.7	88.0	89.2
		Liquid/Slurry and pit storage below animal confinements < 1 month	7.2	9.6	4.8	4.8	15.7	18.1	30.2	45.8	43.4	50.7
		Deep bedding > 1 month	25.3	31.4	16.9	16.9	44.6	49.4	0.7	91.7	88.0	89.2

		Deep bedding< 1 month	3.3				7.8		21.7			
		Solid storage	2.4				4.8		6.0			
		Solid storage – Covered/compacted	2.4				4.8		6.0			
		Solid storage – Bulking agent addition	0.6				1.2		1.8			
		Solid storage – Additives	1.2				2.4		3.0			
		Dry lot	1.2				1.8		2.4			
		Daily spread	0.1				0.6		1.2			
		Composting - In-vessel[3]	0.60									
		Composting - Static pile (Forced aeration)[3]	1.2				2.4		3.0			
		Composting - Intensive windrow[3]	0.6				1.2		1.8			
		Composting – Passive windrow (Unfrequent turning)[3]	1.2				2.4		3.0			
		Pasture/Range/Paddock[1]	0.6									
		Poultry manure without or without litter	NA									
		Aerobic treatment	0.0									
		Burned for fuel	12.1									
	Low Productivity	Uncovered anaerobic lagoon	52.3	58.4	43.6	42.7	63.6	66.2	66.2	69.7	69.7	69.7
		Liquid/Slurry, and Pit storage below animal confinements > 1 month [5]	18.3	22.6	12.2	12.2	32.2	35.7	0.5	66.2	63.6	64.5
		Liquid/Slurry and pit storage below animal confinements < 1 month	5.2	7.0	3.5	3.5	11.3	13.1	21.8	33.1	31.4	36.6
		Deep bedding > 1 month	18.3	22.6	12.2	12.2	32.2	35.7	0.5	66.2	63.6	64.5
		Deep bedding< 1 month	2.4				5.7		15.7			
		Solid storage	1.7				3.5		4.4			
		Solid storage – Covered/compacted	1.7				3.5		4.4			
		Solid storage – Bulking agent addition	0.4				0.9		1.3			
		Solid storage – Additives	0.9				1.7		2.2			

		Dry lot	0.9	1.3	1.7
		Daily spread	0.1	0.4	0.9
		Composting - In-vessel[3]	0.4		
		Composting - Static pile (Forced aeration)[3]	0.9	1.7	2.2
		Composting - Intensive windrow[3]	0.4	0.9	1.3
		Composting – Passive windrow (Unfrequent turning)[3]	0.9	1.7	2.2
		Pasture/Range/Paddock[1]	0.4		
		Poultry manure without or without litter	NA		
		Aerobic treatment	0.0		
		Burned for fuel	8.7		

[1] All values are calculated based on MCFs and B0s reported in Tables 10.17 and 10.16B, respectively. Pasture range and paddock emission factors are based on observation in updated version of Cai *et al.* (2017) database (see Annex 10B.6). No differences were observe for animal type, region or productivity class and are therefore reported as a constant for all animal and productivity categories.

[2] Temp. is an abbreviation for the temperate climate zone

[3]. Composting is the biological oxidation of organic material

[4]. Definitions of manure management systems can be found in Table 10.18

[5]. Emissions for liquid systems are calculated from manure management systems with a 6 month retention time.

TABLE 10.14C
AVERAGE REGIONAL CH_4 EMISSION FACTORS OF SWINE BY CLIMATE ZONE (G CH_4 KG VS^{-1})[6]

Livestock species	Productivity Class	Manure Storage System[4]	Cool				Temperate		Warm			
			Cool Temp. Moist	Cool Temp. Dry	Boreal Moist	Boreal Dry	Warm Temp. Moist	Warm Temp. Dry	Tropical Montane	Tropical Wet	Tropical Moist	Tropical Dry
Growing and Breeding Swine	High Productivity	Uncovered anaerobic lagoon	180.9	202.0	150.8	147.7	220.1	229.1	229.1	241.2	241.2	241.2
		[5]Liquid/Slurry, and Pit storage below animal confinements > 1 month	63.3	78.4	42.2	42.2	111.6	123.6	1.8	229.1	220.1	223.1
		Liquid/Slurry and pit storage below animal confinements < 1 month	18.1	24.1	12.1	12.1	39.2	45.2	75.4	114.6	108.5	126.6
		Deep bedding > 1 month	63.3	78.4	42.2	42.2	111.6	123.6	1.8	229.1	220.1	223.1
		Deep bedding< 1 month	8.3				19.6		54.3			
		Solid storage	6.0				12.1		15.1			
		Solid storage – Covered/compacted	6.0				12.1		15.1			
		Solid storage – Bulking agent addition	1.5				3.0		4.5			
		Solid storage – Additives	3.0				6.0		7.5			
		Dry lot	3.0				4.5		6.0			
		Daily spread	0.3				1.5		3.0			
		Composting - In-vessel[3]	1.51									
		Composting - Static pile (Forced aeration)[3]	3.0				6.0		7.5			
		Composting - Intensive windrow[3]	1.5				3.0		4.5			
		Composting – Passive windrow (Unfrequent turning)[3]	3.0				6.0		7.5			
		Pasture/Range/Paddock[1]	1.4									
		Poultry manure without or without litter	NA									

		Aerobic treatment	0.0									
		Burned for fuel	30.2									
	Low Productivity	Uncovered anaerobic lagoon	116.6	130.2	97.2	95.2	141.8	147.7	147.7	155.4	155.4	155.4
		[5]Liquid/Slurry, and Pit storage below animal confinements > 1 month	40.8	50.5	27.2	27.2	71.9	79.7	1.1	147.7	141.8	143.8
		Liquid/Slurry and pit storage below animal confinements < 1 month	11.7	15.5	7.8	7.8	25.3	29.1	48.6	73.8	69.9	81.6
		Deep bedding > 1 month	40.8	50.5	27.2	27.2	71.9	79.7	1.1	147.7	141.8	143.8
		Deep bedding< 1 month	5.3				12.6		35.0			
		Solid storage	3.9				7.8		9.7			
		Solid storage – Covered/compacted	3.9				7.8		9.7			
		Solid storage – Bulking agent addition	1.0				1.9		2.9			
		Solid storage – Additives	1.9				3.9		4.9			
		Dry lot	1.9				2.9		3.9			
		Daily spread	0.2				1.0		1.9			
		Composting - In-vessel[3]	0.97									
		Composting - Static pile (Forced aeration)[3]	1.9					3.9		4.9		
		Composting - Intensive windrow[3]	1.0					1.9		2.9		
		Composting – Passive windrow (Unfrequent turning)[3]	1.9					3.9		4.9		
		Pasture/Range/Paddock[1]	0.9									
		Poultry manure without or without litter	NA									
		Aerobic treatment	0.0									
		Burned for fuel	19.4									

[1] All values are calculated based on MCFs and B0s reported in Tables 10.17 and 10.16B, respectively. Pasture range and paddock emission factors are based on observation in updated version of Cai *et al.* (2017) database (see Annex 10B.6). No differences were observe for animal type, region or productivity class and are therefore reported as a constant for all animal and productivity categories.

[2] Temp. is an abbreviation for the temperate climate zone

[3]. Composting is the biological oxidation of organic material

[4]. Definitions of manure management systems can be found in Table 10.18

[5]. Emissions for liquid systems are calculated from manure management systems with a 6 month retention time.

TABLE 10.14D AVERAGE REGIONAL CH_4 EMISSION FACTORS OF BUFFALO BY CLIMATE ZONE (G CH_4 KG VS $^{-1}$)													
Livestock species	**Productivity Class**	**Manure Storage System4**	**Cool**				**Temperate**		**Warm**				
			Cool Temp. Moist	**Cool Temp. Dry**	**Boreal Moist**	**Boreal Dry**	**Warm Temp. Moist**	**Warm Temp. Dry**	**Tropical Montane**	**Tropical Wet**	**Tropical Moist**	**Tropical Dry**	

Buffalo		Uncovered anaerobic lagoon	40.2	44.9	33.5	32.8	48.9	50.9	50.9	53.6	53.6	53.6
		Liquid/Slurry, and Pit storage below animal confinements > 1 month[5]	14.1	17.4	9.4	9.4	24.8	27.5	0.4	50.9	48.9	49.6
		Liquid/Slurry and pit storage below animal confinements < 1 month	4.0	5.4	2.7	2.7	8.7	10.1	16.8	25.5	24.1	28.1
		Deep bedding > 1 month	14.1	17.4	9.4	9.4	24.8	27.5	0.4	50.9	48.9	49.6
		Deep bedding< 1 month	1.8				4.4		12.1			
		Solid storage	1.3				2.7		3.4			
		Solid storage – Covered/compacted	1.3				2.7		3.4			
		Solid storage – Bulking agent addition	0.3				0.7		1.0			
		Solid storage – Additives	0.7				1.3		1.7			
		Dry lot	0.7				1.0		1.3			
		Daily spread	0.1				0.3		0.7			
		Composting - In-vessel[3]	0.34									
		Composting - Static pile (Forced aeration)[3]	0.7				1.3		1.7			
		Composting - Intensive windrow[3]	0.3				0.7		1.0			
		Composting – Passive windrow (Unfrequent turning)[3]	0.7				1.3		1.7			
		Pasture/Range/Paddock	0.3									
		Poultry manure without or without litter	NA									
		Aerobic treatment	0.0									
		Burned for fuel	6.7									

[1] All values are calculated based on MCFs and B0s reported in Tables 10.17 and 10.16B, respectively. Pasture range and paddock emission factors are based on observation in updated version of Cai *et al.* (2017) database (see Annex 10B.6). No differences were observe for animal type, region or productivity class and are therefore reported as a constant for all animal and productivity categories.

[2] Temp. is an abbreviation for the temperate climate zone

[3]. Composting is the biological oxidation of organic material

[4]. Definitions of manure management systems can be found in Table 10.18

[5]. Emissions for liquid systems are calculated from manure management systems with a 6 month retention time.

TABLE 10.14E
AVERAGE REGIONAL CH_4 EMISSION FACTORS OF POULTRY BY CLIMATE ZONE ($G\ CH_4\ KG\ VS^{-1}$)

Livestock species	Productivity Class	Manure Storage System	Cool				Temperate		Warm			
			Cool Temperate Moist	Cool Temperate Dry	Boreal Moist	Boreal Dry	Warm Temperate Moist	Warm Temperate Dry	Tropical Montane	Tropic al Wet	Tropical Moist	Tropical Dry

Layer	High productivity (B0=0.39)	Uncovered anaerobic lagoon	156.8	175.1	130.7	128.0	190.7	198.6	198.6	209.0	209.0	209.0
		Liquid/Slurry, and Pit storage below animal confinements > 1 month[5]	54.9	67.9	36.6	36.6	96.7	107.1	1.5	198.6	190.7	193.4
		Liquid/Slurry and pit storage below animal confinements < 1 month	15.7	20.9	10.5	10.5	34.0	39.2	65.3	99.3	94.1	109.7
		Deep bedding > 1 month	NA									
		Deep bedding< 1 month	NA									
		Solid storage	5.2				10.5		13.1			
		Solid storage – Covered/compacted	5.2				10.5		13.1			
		Solid storage – Bulking agent addition	1.3				2.6		3.9			
		Solid storage – Additives	2.6				5.2		6.5			
		Dry lot	2.6				3.9		5.2			
		Daily spread	0.3				1.3		2.6			
		Composting - In-vessel[3]	1.31									
		Composting - Static pile (Forced aeration)[3]	2.6				5.2		6.5			
		Composting - Intensive windrow[3]	1.3				2.6		3.9			
		Composting – Passive windrow (Unfrequent turning)[3]	2.6				5.2		6.5			
		Pasture/Range/Paddock	1.2									
		Poultry manure without or without litter	3.9									
		Aerobic treatment	0.0									
		Burned for fuel	26.1									
	Low productivity (B0=0.24)	Uncovered anaerobic lagoon	96.5	107.7	80.4	78.8	117.4	122.2	122.2	128.6	128.6	128.6
		Liquid/Slurry, and Pit storage below animal confinements > 1 month[5]	33.8	41.8	22.5	22.5	59.5	65.9	0.9	122.2	117.4	119.0
		Liquid/Slurry and pit storage below animal confinements < 1 month	9.6	12.9	6.4	6.4	20.9	24.1	40.2	61.1	57.9	67.5
		Deep bedding > 1 month	NA									
		Deep bedding< 1 month	NA									

		Solid storage	3.2				6.4		8.0			
		Solid storage – Covered/compacted	3.2				6.4		8.0			
		Solid storage – Bulking agent addition	0.8				1.6		2.4			
		Solid storage – Additives	1.6				3.2		4.0			
		Dry lot	1.6				2.4		3.2			
		Daily spread	0.2				0.8		1.6			
		Composting - In-vessel[3]	0.80									
		Composting - Static pile (Forced aeration)[3]	1.6				3.2		4.0			
		Composting - Intensive windrow[3]	0.8				1.6		2.4			
		Composting – Passive windrow (Unfrequent turning)[3]	1.6				3.2		4.0			
		Pasture/Range/Paddock	0.8									
		Poultry manure without or without litter	2.4									
		Aerobic treatment	0.0									
		Burned for fuel	16.1									
Broiler	High productivity (B0=0.36)	Uncovered anaerobic lagoon	144.7	161.6	120.6	118.2	176.1	183.3	183.3	193.0	193.0	193.0
		Liquid/Slurry, and Pit storage below animal confinements > 1 month[5]	50.7	62.7	33.8	33.8	89.2	98.9	1.4	183.3	176.1	178.5
		Liquid/Slurry and pit storage below animal confinements < 1 month	14.5	19.3	9.6	9.6	31.4	36.2	60.3	91.7	86.8	101.3
		Deep bedding > 1 month	NA									
		Deep bedding< 1 month	NA									
		Solid storage	4.8				9.6		12.1			
		Solid storage – Covered/compacted	4.8				9.6		12.1			
		Solid storage – Bulking agent addition	1.2				2.4		3.6			
		Solid storage – Additives	2.4				4.8		6.0			
		Dry lot	2.4				3.6		4.8			

		Daily spread	0.2				1.2		2.4			
		Composting - In-vessel[3]	1.21									
		Composting - Static pile (Forced aeration)[3]	2.4				4.8		6.0			
		Composting - Intensive windrow[3]	1.2				2.4		3.6			
		Composting – Passive windrow (Unfrequent turning)[3]	2.4				4.8		6.0			
		Pasture/Range/Paddock	1.1									
		Poultry manure without or without litter	3.6									
		Aerobic treatment	0.0									
		Burned for fuel	24.1									
	Low productivity (B0=0.24)	Uncovered anaerobic lagoon	96.5	107.7	80.4	78.8	117.4	122.2	122.2	128.6	128.6	128.6
		Liquid/Slurry, and Pit storage below animal confinements > 1 month [5]	33.8	41.8	22.5	22.5	59.5	65.9	0.9	122.2	117.4	119.0
		Liquid/Slurry and pit storage below animal confinements < 1 month	9.6	12.9	6.4	6.4	20.9	24.1	40.2	61.1	57.9	67.5
		Deep bedding > 1 month	NA									
		Deep bedding< 1 month	NA									
		Solid storage	3.2				6.4		8.0			
		Solid storage – Covered/compacted	3.2				6.4		8.0			
		Solid storage – Bulking agent addition	0.8				1.6		2.4			
		Solid storage – Additives	1.6				3.2		4.0			
		Dry lot	1.6				2.4		3.2			
		Daily spread	0.2				0.8		1.6			
		Composting - In-vessel[3]	0.80									
		Composting - Static pile (Forced aeration)[3]	1.6				3.2		4.0			
		Composting - Intensive windrow[3]	0.8				1.6		2.4			
		Composting – Passive windrow (Unfrequent turning)[3]	1.6				3.2		4.0			

		Pasture/Range/Paddock	0.8
		Poultry manure without or without litter	2.4
		Aerobic treatment	0.0
		Burned for fuel	16.1

[1] All values are calculated based on MCFs and B0s reported in Tables 10.17 and 10.16B, respectively. Pasture range and paddock emission factors are based on observation in updated version of Cai *et al.* (2017) database (see Annex 10B.6). No differences were observe for animal type, region or productivity class and are therefore reported as a constant for all animal and productivity categories.

[2] Temp. is an abbreviation for the temperate climate zone

[3]. Composting is the biological oxidation of organic material

[4]. Definitions of manure management systems can be found in Table 10.18

[5]. Emissions for liquid systems are calculated from manure management systems with a 6 month retention time.

TABLE 10.15
MANURE MANAGEMENT METHANE EMISSION FACTORS BY TEMPERATURE FOR SHEEP, GOATS, CAMELS, HORSES, MULES AND ASSES (G CH_4 KG VS^{-1})

Livestock species	Productivity Class	Manure Storage System	Cool				Temperate		Warm			
			Cool Temp. Moist	Cool Temp. Dry	Boreal Moist	Boreal Dry	Warm Temp. Moist	Warm Temp. Dry	Tropical Montane	Tropical Wet	Tropical Moist	Tropical Dry
Sheep	High productivity	Solid storage	2.5				5.1		6.4			
		Dry lot	1.3				1.9		2.5			
		Pasture/Range/ Paddock	0.60									
	Low productivity	Solid storage	1.7				3.5		4.4			
		Dry lot	0.9				1.3		1.7			
		Pasture/Range/ Paddock	0.60									
Goats	High productivity	Solid storage	2.4				4.8		6.0			
		Dry lot	1.2				1.8		2.4			
		Pasture/Range/ Paddock	0.60									
	Low productivity	Solid storage	1.7				3.5		4.4			
		Dry lot	0.9				1.3		1.7			
		Pasture/Range/ Paddock	0.60									
Camels	High productivity	Solid storage	3.5				7.0		8.7			
		Dry lot	1.7				2.6		0.0			
		Pasture/Range/ Paddock	0.60									
	Low productivity	Solid storage	2.8				5.6		7.0			
		Dry lot	1.4				2.1		2.8			
		Pasture/Range/Padd	0.60									

		ock			
Horses	High productivity	Solid storage	4.0	8.0	10.1
		Dry lot	2.0	3.0	4.0
		Pasture/Range/ Paddock	0.60		
	Low productivity	Solid storage	3.5	7.0	8.7
		Dry lot	1.7	2.6	3.5
		Pasture/Range/ Paddock	0.60		
Mules/ Asses	High productivity	Solid storage	4.4	8.8	11.1
		Dry lot	2.2	3.3	4.4
		Pasture/Range/ Paddock	0.60		
	Low productivity	Solid storage	3.5	7.0	8.7
		Dry lot	1.7	2.6	3.5
		Pasture/Range/ Paddock	0.60		

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

Livestock	EFs (kg/head/year)	
	CH_4	
	Range	**mean±SD**
Deer[a]	0.0046~4.1618	0.53±0.99
Reindeer[b]	0.2193~0.3624	0.31±0.06
Rabbits[c]	0.0783~0.2522	0.09±0.04
Fur-bearing animals (e.g., fox, mink)	0.378~0.685	0.62±0.09
Ostrich	0.0016~5.6768	3.74±1.90

Source: Calculated based the country submission of CRF to UNFCCC

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

$$EF_{(T)} = \left(VS_T \bullet 365\right)\left[B_{O(T)} \bullet 0.67 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet AWMS_{(T,S,k)}\right]$$

Where:

$EF_{(T)}$ = annual CH_4 emission factor for livestock category *T*, g CH_4 kg VS^{-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, kg m^{-3}

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

$AWMS_{(T,S,k)}$ = fraction of livestock category *T*'s manure handled using animal waste 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.2-2 through 10A.2-7 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 10.24 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, DC, in the process of estimating enteric methane emissions.

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

EQUATION 10.24A
VOLATILE SOLID EXCRETION RATES

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

Where:

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

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

DC = 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 DC% 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 10.17 where data is from Table 10A-4 through 10A9 of *2006 IPCC guideline*s

MCFs

MCFs are determined for a specific manure management system and represent the degree to which B_o is achieved. Default methane conversion factors (MCFs) are provided in Table 10.18 for different manure management systems. 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 liquid systems and lagoons presented in Table 10.22 include the effect of longer retention times.

Liquid-based systems are sensitive to temperature effects, but average annual MCF values for a specific system will largely be determined by the quantity of VS in the storage system during peak temperature periods (Balde *et al.* 2016). Emissions increase exponentially with increasing temperatures. For this reason monthly temperature variations in combination with timing of storage and application times that largely define annual MCFs rather than average annual temperatures.

Climate zones are used to differentiate variations in MCFs associated with ranges and annual monthly temperature variability. Detailed definitions of climate zones and a decision tree to determine in what climate zone a specific region falls, can be found in , Annex 3A.5, Figure 3A.5.2. of of *the 2006 IPCC Guideline, .*

In cases in which countries lie in multiple climate zones, it is *good practice* for compilers, if possible, to dissagregate livestock populations by climate zone; However when it is not possible, compilers should select the dominant climate zone in their country or region.

Further, in cases that countries have information available on their manure spreading practices (number of times that manure storages are emptied per year) and have monthly temperature profiles it is *good practice* that they customize MCF calculations based on their monthly temperature profiles according to the example provided in Annex 10A.4. Likewise for cases in which manure is maintained in the animal housing, compilers may wish to calculate the MCF considering the temperature profile of the housing. An example of how to derive an MCF for a liquid system is provided in Annex 10A.2 and a simple spreadsheet model is available for download from the ipcc website **(Material available to reviewers).**

For manure deposited by grazing animals onto pasture, ranges and paddocks, it is recommended to a value that is consistent with the Emission Factor provided in the Tier 1 tables that provides a single emission factor per unit of volatile solid excretion as an analysis of 45 data showed there was no significant difference between climatic zones nor were there differences per animal category. Therefore, the MCF reported in Table 17B must be used in conjunction with a single B_0 value of 0.19 m^3 CH_4 kg^{-1} of VS excreted, derived from the experimental results described in Annex 10B.6. This Emission Factor is considered to be more accurate than emission factors estimated from regionally based MCFs and animal category based B_0.

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:

- Duration of storage and timing of application;
- Information on manure treatment and VS entering the storage system;
- Feed and animal characteristics at the measurement site (see Section 10.2 for the type of data that would be pertinent);
- Determination of the amount of manure left in the storage facility after emptying (methanogenic inoculum); Monthly temperature in the storage.

TABLE 10.16B
DEFAULT VALUES FOR B_0 (m^3 CH_4 kg^{-1} VS)

Category of animal	Region					
	North America	Western Europe	Eastern Europe	Oceania	Other Regions	
					High productivity	Low productivity
Dairy cattle	0.24				0.24	0.13
Non dairy cattle	0.19	0.18	0.17	0.17	0.18	0.13
Buffalo	0.10				0.10	0.10
Swine	0.48	0.45	0.45	0.45	0.45	0.29
Chicken-Layer	0.39				0.39	0.24
Chicken-Broilers	0.36				0.36	0.24
Sheep	0.19				0.19	0.13
Goats	0.18				0.18	0.13
Horses	0.30				0.30	0.26
Mules/ Asses	0.33				0.33	0.26
Camels	0.26				0.26	0.21
All Animals PRP	0.19					

Table 10.17
Methane Conversion Factors for manure management systems

System[4]		MCFs by climate zone										Source and comments
		Cool				Temperate		Warm				
		Cool Temperate Moist	Cool Temperate Dry	Boreal Moist	Boreal Dry	Warm Temperate Moist	Warm Temperate Dry	Tropical	Tropical Wet	Tropical Moist	Tropical Dry	
Uncovered anaerobic lagoon		60%	67%	50%	49%	73%	76%	76%	80%	80%	80%	Judgement of IPCC Expert Group utilizing a 12 month retention time and the equations and parameters presented in Mangino *et al.* (2001). Solid-liquid separation that removes VS and diverts it to aerobic/solid management should be considered when calculating the VS loading rate into liquid systems.
Liquid/Slurry, and Pit storage below animal confinements	1 Month	6%	8%	4%	4%	13%	15%	25%	38%	36%	42%	Judgement of IPCC Expert Group. See Annex 10B.5 for additional details. A reduction of 40% due to crust cover (40%) may be applied only when a thick, dry, crust is present.1

	3 Month	12%	16%	8%	8%	24%	28%	43%	61%	57%	62%	The tavg C for Cool Temperate Moist, Cool Temperate Dry, Warm Temperate Moist, Warm Temperate Dry, Tropical, Tropical Wet, Tropical Moist, Tropical Dry were 4.6, 5.8, 13.9, 14.0, 21.5, 25.9, 25.2, 25.6 respectively.
	4 Month	15%	19%	9%	9%	29%	32%	50%	67%	64%	68%	Solid-liquid separation that removes VS and diverts it to aerobic/solid management should be considered when calculating the VS loading rate into liquid systems.
	6 Month	21%	26%	14%	14%	37%	41%	0.59%	76%	73%	74%	
	12 Month	31%	42%	21%	20%	55%	64%	73%	80%	80%	80%	
Cattle and Swine deep bedding (cont.)[5]	> 1 month	21%	26%	14%	14%	37%	41%	0.59%	76%	73%	74%	Judgement of IPCC 2006 Expert Group in combination with Mangino *et al.* (2001). Values are consistent with liquid systems. Values presented here are consistent with a 6 month retention time, however compilers should take into account country-specific retnetions times when possible.

Cattle and Swine deep bedding	< 1 month	2.75%	6.50%	18%	Judgement of IPCC 2006 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.
Solid storage[6]		2.00%	4.00%	5.00%	Expert judgement based on IPCC (2006) and update supported by Pardo *et al.* (2015). Emissions in temperate climate can be double than in cool climate
Solid storage – Covered/compacted[6]		2.00%	4.00%	5.00%	Expert judgement based on Pardo *et al.,* (2015). Emissions in the same range than solid storage.
Solid storage – Bulking agent addition[6]		0.50%	1.00%	1.50%	Expert judgement based on Pardo *et al.* (2015). Estimated reduction of 75% due to bulking agent addition
Solid storage – Additives[6]		1.00%	2.00%	2.50%	Expert judgement based on Pardo *et al.* (2015). Estimated reduction of 50% due to bulking agent

				addition
Dry lot	1.00%	1.50%	2.00%	Judgement of IPCC 2006 Expert Group in combination with Hashimoto and Steed (1993)
Daily spread	0.10%	0.50%	1.00%	Hashimoto and Steed (1993); Hashimoto and Steed (1993)
Anaerobic digester	See approach to calculation of MCF provided below.			Details and sources cited in text following the current Table.
Composting - In-vessel[b]	0.50%			Judgement of IPCC 2006 Expert Group and Amon *et al.* (1998). MCFs are less than half of solid storage. Not temperature dependant.
Composting - Static pile (Forced aeration)[b,6]	1.00%	2.00%	2.50%	Expert judgement update based on Pardo *et al.* (2015). Estimated reduction of 50% compared to solid storage. Previously it was considered "Not temperature dependent" but now temperature influence has been considered
Composting - Intensive windrow[b]	0.50%	1.00%	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 (Unfrequent turning)[3,6]	1.00%	2.00%	2.50%	Expert judgement update based on Pardo *et al.* (2015). Estimated reduction of 50% compared to solid storage. Previous MCFs have been modified as they could underestimate CH4 emissions
Pasture/Range/Paddock[2]	0.45% (see footnote)			Based on updated version of Cai *et al.* (2017) database (see Annex 10B.6)
Poultry manure with and without litter	1.50%			Judgement of 2006 IPCC Expert Group. MCFs are similar to sol id storage or to dry lot but with generally constant warm temperatures.
Aerobic treatment	0.00%			Judgement of 2006 IPCC Expert Group. 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.
Burned for fuel	10.00%	Judgement of IPCC 2006 Expert Group in combination with Safley *et al.* (1992)

[1]The initial judgement of IPCC Expert Group supported by additional new research. See Annex B.7 for additional details. A reduction of 40% due to crust cover (40%) may be applied only when a thick, dry, crust is present.REFERENCES : Aguerre et al. 2012; Nielsen et al. 2013; Vanderzaag et al. 2008

New information suggests that a solid cover reduces CH_4 emissions by 25 to 50% (range: 0 to 90%)

REFERENCES: Amon *et al.* (2006), Amon *et al.* (2007); Clemens *et al.* (2006); Guarino *et al.* (2006), Matulaitis *et al.* (2015), Misselbrook *et al.* (2016), VanderZaag *et al.* (2009), Hou *et al.* (2015), VanderZaag *et al.* (2008)

[2] Pasture Range and Paddock MCFs must always be used in conjunction with a B0 value of 0.19 m^3 CH_4 kg^{-1} of VS excreted to maintain consistency with the data the in updated version of Cai et al. (2017) database (see Annex 10B.6)

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

[4] 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.

[5]. Suggested default values are equivalent to liquid systems with 6 month retention time if retention times are unknown

[6].. Sources and assumptions to calculate MCF values for *Solid storage categories and composting (static pile and passive windrows)* are detailed in Annex 10 B.7.

CH_4 emissions from biogas digesters

The methane emission from the biogas digesters include the unused biogas (can be defined as leakage) and emissions from storage of digestion residues. The MCF calculation from biogas digesters should be based on the following equation

EQUATION 10.24B.
CALCULATION OF MCF FOR BIOGAS DIGESTERS

$$MCF = \frac{v_{CH4,prod} - v_{CH4,used} - v_{CH4,\ flared} + MCF_{residues} \bullet \left(B_0 - v_{CH4,prod}\right)}{B_0}$$

Where:

MCF = effective methane conversion factor for the combination "digester + storage, %

$v_{CH4,\ prod}$ = specific volume of methane produced in the digester, m3 CH4 kg^{-1}VS

vch4, used = specific volume of methane used for energy production, m3 CH4 kg^{-1}VS

$v_{CH4,\ flared}$ = specific volume of methane flared, m3 CH4 kg^{-1}VS

$MCF_{residues}$ = methane conversion factor for the storage of digested manure, %

B_0 = maximum methane producing capacity for manure produced by livestock category T, m3 CH4 kg^{-1} of VS excreted

In practice the residence time necessary to fully exploit the maximum methane producing capacity B_o is not reached in the gas collection system. In the following the difference, i. e. the potentially still purgeable amount of gas ($B_o - \upsilon_{CH4,\ prod}$), is denoted as "potential off gas" the ratio of which to B_o is described by the entity μ_{offgas}:

EQUATION 10.24C
CALCULATION OF RELATIVE AMOUNT OF POTENTIAL OFF GAS RELATED TO B0

$$\mu_{offgas} = \frac{B_0 - v_{CH4,\ prod}}{B_0}$$

Where:

μ_{offgas} = elative amount of potential off gas related to B_o (with $0 \le \mu_{offgas} \le 1$ m^3 m^{-3})

B_0 = maximum methane producing capacity per kg of VS, m^3 CH_4 kg^{-1}VS

$v_{CH4,\ prod}$ = specific volume of methane produced in the digester, m^3 CH_4 kg^{-1}VS

In practice, the amount of offgas ,μ_{offgas} is not given as a share of the maximum methane producing capacity B_0, but as a share of the amount of gas usable for energy production. Hence, a new entity v_{offgas} can be defined which is closely related to μ_{offgas}

For the μ_{offgas}, it can be calculated as follows:

EQUATION 10.24D
CALCULATION OF RELATIVE AMOUNT OF POTENTIAL OFF GAS RELATED TO Bo

$$\mu_{offgas} = \frac{v_{offgas}}{1 + v_{offgas}}$$

Where:

μ_{offgas} = relative amount of potential offgas related to B_o (with $0 \leq \mu_{offgas} \leq 1\ m^3\ m^{-3}$)

v_{offgas} = relative amount of potential offgas related to $CH_{4,\ prod}$ (with $0 \leq \mu_{offgas} \leq 1\ m^3\ m^{-3}$)

:

EQUATION 10.24E
CALCULATION OF RELATIVE AMOUNT OF POTENTIAL OFF GAS RELATED TO CH_4 PRODUCTION

$$v_{offgas} = \frac{B_0 - v_{CH4,prod}}{v_{CH4,prod}}$$

Where:

v_{offgas} = relative amount of potential off gas related to CH_4,production (with $0 \leq \mu_{offgas} \leq 1\ m^3\ m^{-3}$)

B_0 = maximum methane producing capacity per kg of VS, $m^3\ CH_4\ kg^{-1}VS$

$v_{CH4,prod}$ = specific volume of methane produced in the digester , $m^3\ CH_4\ kg^{-1}VS$

The difference $v_{CH4,pro} - v_{CH4,used} - v_{ch4,\ fared}$ in equation 10.26 is part of the digester's methane balance (related to VS input) which can be completed by the methane loss $\upsilon_{CH4,\ leak}$ due to leakage. The leakage-caused loss of methane $\upsilon_{CH4,\ leak}$ can be described by the leakage rate L_{prod} of the digester:

EQUATION 10.24F
CALCULATION OF METHANE LEAKAGE RATE OF DIGESTER

$$L_{prod} = \frac{v_{CH4,\ leak}}{v_{CH4,prod}}$$

Where:

L_{prod} = leakage rate of the digester, related to $CH_{4,\ prod}$ (with $0 \leq L_{prod} \leq 1$ m^3 m^{-3})

$v_{CH4,leak}$ = specific volume of methane due to leakage and maintenance works, m^3 CH_4 kg^{-1} VS

In order to give the effective methane conversion factor of the combination, "digester + residue storage" as a function of the three parameters, relative amount of potential off gas, "leakage rate" and "MCF of the residue storage", methane conversion factor of the combination, "digester + residue storage" can be calculated as following equation 10.30A :

EQUATION 10.24G.
CALCULATION OF METHANE CONVERSION FACTOR

$$\text{MCF} = \left(1 - \mu_{offgas}\right) \bullet L_{prod} + \mu_{offgas} \bullet MCF_{residues}$$

Where:

MCF = effective methane conversion factor for the combination "digester + storage",%

μ_{offgas} = relative amount of potential off gas related to Bo (with $0 \leq \mu offgas \leq 1$ m^3 m^{-3})

L_{prod} = leakage rate of the digester, related to υCH_4, prod (with $0 \leq Lprod \leq 1$ m^3 m^{-3})

$MCF_{residues}$ = methane conversion factor for the storage of digested manure ,% . When a gas tight storage is included: $MCF_{residues}$ = 0; otherwise $MCF_{residues}$ is same to the storage of raw manure.

For a gastight residue storage MCF_{residues} is zero, methane conversion factor can be calculated as equation or equation 10.30B

EQUATION 10.24H.
CALCULATION OF METHANE CONVERSION FACTOR IN GASTIGHT STORAGE

$$\mathbf{MCF} = \left(1 - \boldsymbol{\mu}_{offgas}\right) \bullet \boldsymbol{L}_{prod}$$

Where:

MCF = effective methane conversion factor for the combination "digester + storage",%

μ_{offgas} = relative amount of potential off gas related to Bo (with $0 \leq \mu offgas \leq 1$ m^3 m^{-3})

L_{prod} = leakage rate of the digester, related to υCH_4, prod (with $0 \leq Lprod \leq 1$ m^3 m^{-3})

For the leakage rate L_{prod}, Rösemann *et al.* (2017) proposes a general value of 1 %..However, the 10% of leakage rate L_{prod}, was recommended in. T able 10A-4 to T able 10A-9 of 2006 IPCC guideline. Given the quality difference of biogas digesters, it is recommended to use 1% for advanced commercial biogas digesters, and 10% for low quality biogas digesters , respectively.

10.4.3 Choice of activity data

This section is an elaboration

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 total 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 as defined in Volume 4, Chapter 3, Annex 3A.5, Figure 3A.5. or the simplified version found in Annex 10A.2 of this Chapter. 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 10.19 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 15% 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, if manure is managed in multiple systems, it is good practice to report the respective CH_4 emissions in each 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.

TABLE 10.18
DEFINITIONS OF MANURE MANAGEMENT SYSTEMS

System	Application to Animal Categories	Definition

Pasture/Range/Paddock	All animals	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread	all animals	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Solid storage	All animals	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. Solid stores can be covered or compacted. In some cases, bulking agent or additives are added .
Solid storage-Covered/compacted	All animals	Similar to solid storage, but the manure pile is a) covered with a plastic sheet to reduce the surface of manure exposed to air and/or b) compacted to increase the density and reduce the free air space within the material.
Solid storage - Bulking agent addition	All animals	Specific materials (bulking agents) are mixed with the manure to provide structural support. This allows the natural aeration of the pile, thus enhancing decomposition. (e.g. sawdust, straw, coffee husks, maize stover)
Solid storage - Additives	All animals	The addition of specific substances to the pile in order to reduce gaseous emissions. Addition of certain compounds such as attapulgite, dicyandiamide or mature compost have shown to reduce N_2O emissions; while phosphogypsum reduce CH_4 emissions
Dry lot	All animals with the exception of swine and poultry (fur-beagin animals,	A paved or unpaved open confinement area without any significant vegetative cover. Dry lots do not require the addition of bedding to control moisture. Manure may be removed periodically and spread on fields.
Liquid/Slurry [a]	Cattle, poultry and swine, .	Manure is stored as excreted or with some minimal addition of water or bedding material in tanks or ponds outside the animal housing. Manure is removed and spread on fields once or more in a calendar year. Manure is agitated before removal from the tank/ponds to ensure that most of the VS are removed from the tank..
Uncovered anaerobic lagoon	Cattle (mainly dairy) and swine, poultry.	A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoons have a lower depth and a much larger surface compared to liquid slurry stores. 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 supernatant water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields.
Pit storage below animal confinements	Cattle, poultry and swine.	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. Manure may be pumped out of the storage to a secondary storage tank multiple times in one year, or stored and applied directly to fields. It is assumed that VS removal rates on tank emptying are >90%.

Anaerobic digester		All animals	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Codigestion with waste or purpose grown crops can occur. 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. After anaerobic digestion, digestate is stored in either open or closed storage tanks or open earthen basins for periods less than one year prior to being spread on fields. Volatile solid removal rates are typically >80%
Burned for fuel		Mainly cattle, extensive systems	The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel.
Deep bedding		Cattle, sheep and swine,	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. Manure may undergo periods where animals are present and are actively mixing the manure, or periods in which the pack is undisturbed.
Composting	In-vessel[a]	Cattle, sheep, swine and other animals	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.
	Static pile		Composting in piles with forced aeration but no mixing, with runoff/leaching containment.
			Composting in piles with forced aeration but no mixing, without runoff/leaching containment.
	Intensive windrow[a]		Composting in windrows with regular (at least daily) turning for mixing and aeration, runoff/leaching containment
			Composting in windrows with regular (at least daily) turning for mixing and aeration, no runoff/leaching containment
	Composting - Passive windrow[a]		Composting in windrows with infrequent turning for mixing and aeration, with runoff/leaching.
			Composting in windrows with infrequent turning for mixing and aeration, no runoff/leaching.
Poultry manure with litter		Poultry	Similar to cattle and swine deep bedding except usually not combined with a dry lot or pasture. Typically used for all poultry breeder flocks, for alternative systems for layers and for the production of meat type chickens (broilers) and other fowl. Litter and manure are left in place with added bedding during the poultry production cycle and cleaned between poultry cycles, typically 5 to 9 weeks in productive systems and greater in lower productivity systems.
Poultry manure without litter		Poultry	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. Some intensive poultry farms installed the manure belt under the cage, where the manure is dried inside housing.

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] Natural crusts and covers on manure management systems can impact emissions of direct N_2O, CH_4 and NH_3, With NH_3, N_2O and CH_4 emission, the effect of the cover depends upon characteristics of cover material.

Additional information on manure management system definitions and comparison to the EMEP/EEA AIR POLLUTANT EMISSION INVENTORY GUIDEBOOK 2016 manure management system definitions can be found in Table 10A.2-10

10.4.4 Uncertainty assessment

No refinement in this section

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

No refinement in this section

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 based on updated N excretion, updated emission factors for N_2O emissions, as well as updated NH_3 volatilization and leaching factors. This section also details the principles of N flow and the connection between IPCC N_2O reporting and NH_3 and NOx reporting required for UNECE countries.

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). Direct and indirect N_2O emissions generated by manure managed in other systems and following its application to soils are also 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 ammonium nitrogen during manure collection and storage depends primarily on oxygen supply, time, and on temperature. Simple forms of organic nitrogen such as urea (mammals) and uric acid (poultry) are rapidly mineralized to ammonium nitrogen, which is converted to ammonia under alkaline conditions. Ammonia is highly volatile and easily diffused into the surrounding air (Asman *et al.* 1998; Monteny & 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. Emissions of nitrogen compounds from grazing livestock are considered separately in Chapter 11, Section 11.2, *N_2O Emissions from Managed Soils*.

In the case of co-digestion of animal manures with additional organic residues, energy crops, additional N enters the system. This additional N source also emits N_2O during the storage, and must be considered in the section "N_2O emissions from manure management". The N in co-digestates with manure should be deducted in the sections "Energy" and/or "Waste" to avoid doubling estimation .

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

This section is an update/elaboration

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 (A and B)

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 10.25A). 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.2-2 to 10A.2-7 for default management system allocations). In this section Tier 1A and Tier 1B approaches are represented in single equations. It is recommended to consult the methane and enteric fermentation sections to clarify how to implement the Tier 1B approach, if that is the approach selected.

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 in detail 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 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.2-2 to 10A.2-7 should be applied. Detailed information on how to characterise the livestock population for this source is provided in Section 10.2.

In the case of anaerobic digestion of animal manures with additional organic residues it is essential to estimate the additional N input from these organic residues and the respective N_2O emissions.

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 carefully consider the fraction of manure that is managed in each type of system. If manure is managed in multiple system, it is good practice to estimate N_2O emissions from all systems.

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

EQUATION 10.25A
DIRECT N2O EMISSIONS FROM MANURE MANAGEMENT

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

Where:

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

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

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

$AWMS_{(T,S,P)}$ = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless; to consider productivity class P, if using a Tier 1B approach

$EF_{3(S)}$ = 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

P = productivity class, high or low, to be considered if using the Tier 1B approach

44/28 = conversion of N_2O-$N_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions

As is the case in the calculation of methane emission, countries may choose to consider if they have signficantly different production systems in their country and apply a Tier 1B approach. In this case, compilers should consider the productivity class of their animal system as included in thecalculation of N_2O 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 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 is required. See Chapter 11, Section 11.2 for procedures to calculate N_2O emissions from managed manure nitrogen applied to soils. Additional guidance on ensuring consistency in the mass balance approach and between emissions from manure in the source category *N_2O Emissions from Manure Management* and *N_2O Emissions from Managed Soils* is given in Section 11.5.6 *Consistency of nitrogen flows*.

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 10.32A). 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.2-2 to 10A.2-7) and default fractions of N losses from manure management systems due to volatilisation (see Table 10.24):

EQUATION 10.26A
N LOSSES DUE TO VOLATILISATION FROM MANURE MANAGEMENT

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

Where:

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

$N_{(T,P)}$ = number of head of livestock species/category *T* in the country, production level P if using a Tier 1 approach

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

P = productivity class, high or low, to be considered if using the Tier 1B approach

$AWMS_{(T,S)}$ = 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*, %

There are 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, pens, in over-wintering areas or feeding pens used during dormant growth periods for pastured animals. 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 & 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). Table 10.22 contains leaching loss fractions that may be applied under very specific circumstances. Leaching can be estimated using these fractions in cases in which manure is uncovered on permeable soil, or where runoff may occur to permeable soil and runoff is not collected in a impermeable basin and redistributed to agricultural fields. Leaching losses are estimated only in cases in which manure nitrogen is being lost to the environment and not accounted for in any other N flows. Further research is needed in this area to improve the estimated losses and the conditions and practices under which such losses occur however an estimate may be provided as.

EQUATION 10.26B
N LOSSES DUE TO LEACHING FROM MANURE MANAGEMENT

$$N_{leach-MMS} = \sum_{S}\left[\sum_{T,P}\left[\left(N_{(T,P)} \bullet Nex_{(T,P)} \bullet AWMS_{(T,S,P)}\right) \bullet \left(\frac{Frac_{LeachMS}}{100}\right)_{(T,S)}\right]\right]$$

Where:

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

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

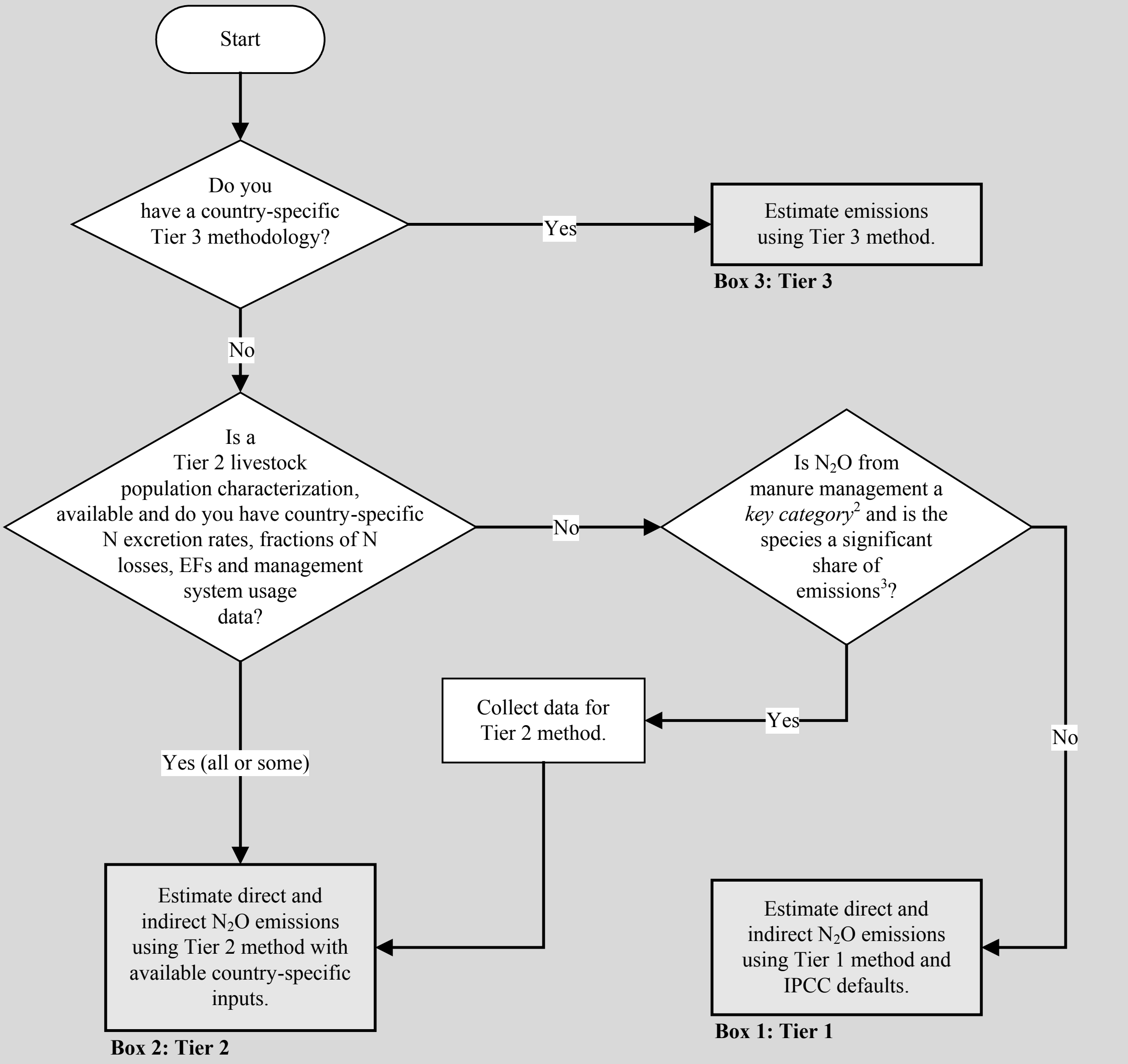
$Nex_{(T,P)}$ = annual average N excretion per head of species/category *T* in the country, kg N $animal^{-1}$ yr^{-1}

P = productivity class, high or low, to be considered if using the Tier 1B approach

$AWMS_{(T,S,\ P)}$ = 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 for livestock category *T* that os leached from the manure management system *S*, % (from Table 10.22)

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 variables. For example, the use of country-specific nitrogen excretion rates for livestock categories would constitute a Tier 2 method. 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. It is good practice to check N balance in a Tier 2 approach. 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). National NH_3 emission inventories developed by some countries could be used for Tier 2 estimation of NH_3 volatilisation from manure management systems. For countries reporting emissions of NH_3 and NOx to the UN-ECE Convention on Long-Range Transboundary Air Pollution (UN-ECE LRTAP) using a Tier 2 approach as described in the EEA (2016) emission inventory guidebook, it is good practice to report volatilization of NH_3 and NO_x in consistency to the data reported to the UN-ECE.

Equation 10.28 should be used where there is country-specific information on the fraction of nitrogen loss due to leaching and runoff from manure management systems available. When country specific information is available, N losses from leaching and runoff from manure management can be considered part of a Tier 2 or Tier 3 method.

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

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

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}

$AWMS_{(T,S)}$ = 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, derived from country specific data, to be developed specifically for regions with high rainfall rates and outdoor uncovered manure pens.

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 N2O 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 subtracted 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

This section is an update

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 characterization. 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

$$Nex_{(T,P)} = N_{rate(T,P)} \bullet \frac{TAM_{(T,P)}}{1000} \bullet 365$$

Where:

$Nex_{(T,P)}$ = annual N excretion for livestock category *T*, kg N animal^{-1} yr^{-1} (production level P if using a Tier 1 approach

$N_{rate(T,P)}$ = default N excretion rate, kg N (1000 kg animal mass)$^{-1}$ day^{-1} for animal category T (and production level P, if using a Tier 1B (see Table 10.19)

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

P = productivity class, high or low, to be considered if using the Tier 1B approach

Default TAM values are provided in Annex 10A.1 and 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. Generally, 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)

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

Where:

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

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

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

365 = Number of days in a year.[5]

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 10.32A, 10.32B and 10.33A, 10.33B, 10.33C, 10.33D and 10.33E can be used to calculate the variables for nitrogen intake and nitrogen retained for use in Equation 10.31. The total annual nitrogen intake rate is derived as follows:

EQUATION 10. 32A
N INTAKE RATES FOR CATTLE

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

EQUATION 10. 32B
N INTAKE RATES FOR SWINE AND POULTRY

$$N_{intake(T,i)} = DMI_i \bullet \left(\frac{\frac{CP\%}{100}}{6.25} \right)$$

Where:

[5] Consideration should be taken of periods between production cycles, particularly for animal categories that may have multiple annual growth cycles

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

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} (used in conjunction with Tier 2 gross energy calculation for cattle, sheep or goats)_

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.

DMI_i = dry matter intake in kg of dry matter per growth stage i

CP% = percent crude protein in dry matter of diet, input

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

The daily value can be converted to a total N input per year or per growth stage by multiplying either by 365 or by the length of the growth period of interest.

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

Category of animal	Region																		
	North Am.	Western Eur.	Eastern Eur.	Oceania	Latin America			Africa			Middle East			Asia			India sub-continent		
					Mean	High P.[1]	Low P.[1]	Mean	High P.	Low P.	Mean	High P.	Low P.	Mean	High P.	Low P.	Mean	High P.	Low P.
Dairy cattle[4]	0.600	0.490	0.410	0.720	0.420	0.330	0.570	0.440	0.410	0.550	0.350	0.380	0.370	0.520	0.510	0.490	0.670	0.700	0.540
Other cattle[4]	0.36	0.42	0.47	0.46	0.36	0.45	0.30	0.43	0.42	0.44	0.70	0.63	0.75	0.38	0.36	0.38	0.44	0.63	0.40
Mature cows	0.35	NR	0.39	0.46	0.30	0.38	0.29	0.38	0.40	0.37	0.47	0.44	0.49	0.32	0.30	0.31	0.44	0.48	0.43
Growing cattle	0.36	0.43	0.55	0.36	0.39	0.49	0.32	0.48	0.45	0.48	0.76	0.72	0.83	0.47	0.42	0.45	0.62	0.68	0.59
Bulls	0.27	0.39	0.32	0.55	0.22	0.27	0.22	0.31	0.31	0.34	0.41	0.37	0.45	0.28	0.23	0.34	0.31	0.39	0.31
Feedlot Cattle	0.39	NR	NR	NR	0.49	0.46	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Buffalo[4]	NR	0.45	0.39	NR	0.47			0.53			0.50			0.48			0.65		
Swine[3]	0.41	0.65	0.66	0.54	0.73	0.61	0.84	0.39	0.31	0.47	0.65	0.67	0.63	0.62	0.58	0.65	0.68	0.66	0.71
Finishing	0.48	0.78	0.80	0.73	0.89	0.77	1.00	0.44	0.37	0.51	0.72	0.75	0.68	0.70	0.68	0.72	0.77	0.77	0.77
Breeding	0.25	0.38	0.37	0.31	0.44	0.35	0.52	0.27	0.20	0.34	0.41	0.40	0.42	0.39	0.35	0.43	0.43	0.38	0.47
Poultry[3]	1.41	1.07	0.92	1.42	1.85	1.13	2.57	1.27	1.16	1.38	1.48	1.21	1.75	1.60	0.99	2.21	1.70	1.46	1.95
Hens >/= 1 yr	1.07	0.97	0.77	1.02	1.72	1.05	2.40	1.14	0.99	1.28	1.30	0.95	1.65	1.42	0.91	1.94	1.67	1.53	1.80
Pullets	0.73	0.64	0.57	0.76	1.88	0.72	3.03	1.20	0.72	1.67	1.36	0.69	2.03	1.72	0.62	2.83	1.64	0.96	2.33
Broilers	1.59	1.24	1.09	1.59	2.06	1.21	2.90	1.43	1.34	1.53	1.67	1.39	1.95	1.99	1.28	2.71	1.85	1.46	2.23
Turkeys[5]	0.74																		
Ducks[5]	0.83																		
Sheep[5]	0.42	0.85	0.9	1.13	1.17														

Goats[5]	0.45	1.28	1.28	1.42	10.00
Horses[5] and mules and asses	0.3	0.26	0.3	0.3	0.46
Camels[5]	0.38				0.46

1. High P and Low P refer to high and low productivity required for Tier 1B methodology
2. NE is reported when values are not estimated, due to their not being adequate differences between high and low productivity production systems and NR refers to situations in which these animal categories do not occur in these regions.
3. Values are taken from FAO GLEAM databases (FAO 2017). High and low estimates are simplified extracts from the model database and may be prone to refinement in the final draft. Means of high and low productivity systems are simple means and will be refined in the final order draft.
4. Values are derived from diets used in the calculation of enteric fermentation Tier 1 emission factors.
5. Values are from Table 10.19 of the *2006 IPCC Guidelines* .

TABLE 10.20A
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) [1]

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).

[1] More complete, regionally specific data can be found for cattle and buffalo in Annex 10A.2, Table 10A.2-1C through 10A.2-1E. Further information will be provided for swine and poultry in the final draft of this refinement.

The total nitrogen retained for Cattle is derived as follows:

EQUATION 10.33A
N RETAINED RATES FOR CATTLE

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

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 and 7.03 = constants from Equation 3-8 in NRC (1996)

1000 = conversion from g protein to kg protein

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)$^{-1}$

The annual fraction of 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.

Example of Tier 2 method for estimating nitrogen excretion for pigs

The nitrogen excretion rate depends on the balance between the animal's feed N intake and its N retention in tissue. Different categories of animals (e.g. adult females, adult males and growing pigs) can have quite different N requirements depending on, for example, their growth rates, lactation rates and yields (MacLeod *et al.* 2013). Likewise, the N retention rates can be different among different animal categories. Thus, when following a Tier 2 approach for estimating nitrogen excretion for pigs, it is a good practice to include N excretion estimations for at least the pig categories listed in Table 10.2

For breeding pigs, if inventory compilers have detailed information about feed, breeding statistics (piglets born and weaned and proportions of sows entering the breeding herd (optional) N retention may be calculated as follows:

EQUATION 10.33B
N RETENTION RATES FOR BREEDING SOWS

$$N_{retention} = N_{gain} + N_{weaned\ piglets}$$

Where:

$N_{retention}$ = amount of N retained by the animal (in kg $animal^{-1}$ $year^{-1}$)

N_{gain} = amount of N retained in the sow (in kg $animal^{-1}$ $year^{-1}$)

$N_{weaned\ piglets}$ = amount of N in piglets weaned (in kg $animal^{-1}$ $year^{-1}$)

Assuming piglets weight on average 4.5 kg at birth and 7.5 kg at weaning with an N content of 0.024 kg kg^{-1}. Default values for annual N retention rates for breeding sows

Table 10.20B

Default parameters for calculating breeding swine N retention

N_{gain} (kg $animal^{-1}$ $year^{-1}$)	$N_{weaned\ piglets}$ (kg $animal^{-1}$ $year^{-1}$)
0.77	4.14

Assuming 2.5 reproductive cycles per year, 23 total piglets, total weight gain sow + piglets = 133.5 kg, weight of piglets at birth = 103 kg, weight of piglets at weaning = 172.5 kg. N gain associated with weight gain of sow (sow weight gain – piglet weight at birth) = 0.0255 kg kg^{-1}. N associated with piglets = 0.024 kg kg^{-1}. Additional information used in the development of parameters for estimating N retention in breeding swine can be found in Tables A.2-9A and A.2-9B of the Annexes for this Chapter.

In estimating N excretion by breeding sows (Equation 10.33B), the following considerations need to be taken into account:

- The reproductive cycle of a breeding sow includes gestation (114 days), lactation (21 to 28 days) and return to estrus/mating (7 days). Thus, one reproductive cycle normally lasts between 142 to 149 days and a sow can then have between 2.45 to 2.57 reproductive cycles per year.

- It is expected that the sow will gain between 10 to 15 kg of body weight during the first four or five reproductive cycles (between 25 to 38.6 kg of body weight per year). Thus during their first two years as reproductive sows, the amount of N retained in the animal (in kg animal^{-1} year^{-1}) will range from 0.64 to 1.0, based on the estimate of N contents of fattening pigs and pigs for reproduction of around 0.0255 kg kg^{-1} (Everts & Dekker 1995; LfL 2013; Dämmgen *et al.* 2017). A higher estimate (1.44 kg animal^{-1} year^{-1}) was presented by Poulsen and Kristensen (1998), probably to account for the fact that sow weight gain is mostly represented by lean weight gain, of greater N content than that of fattening pigs.
- The amount of piglets weaned per sow per year ranges from 22 to 25 piglets and their weight ranges from 6.5 kg to 8.0 kg when weaned at 21 and 28 days, respectively (Gfe, 2008) and their N retention (kg kg^{-1} of body weight) has been reported to be 0.024 (Poulsen & Kristensen 1998). Thus, N retention in the weaned piglets can range from 3.43 to 4.8 kg per sow per year.

For the calculation of the $N_{retention\_frac(T)}$, the daily N retention can be calculated by dividing the result of equation 10.33B by the total number of days in the gestational and weaning periods to provide a daily N retention in Kg N day^{-1}.

For estimating N retention by growing animals, the following approach may be followed:

EQUATION 10.33C
N RETENTION RATES FOR GROWING PIGS

$$N_{retention_{(i)}} = \sum_i (BW_{Final_{(i)}} - \mathrm{BW}_{Initial_{(i)}}) \bullet N_{gain_{(i)}}$$

Where:

$N_{retention(i)}$ = amount of N retained in animal (in kg animal^{-1}) per defined growth stage i

$BW_{Final(i)}$ = Live weight of the animal at the end of the stage (kg) per defined growth stage i

$BW_{Initial}$ = Live weight of the animal at the beginning of the stage (kg) per defined growth stage i.

N_{gain} = fraction of N retained at a given BW, the fraction should be calculated for the final BW of the phase. For example a finishing hog that weighed 109 kg at slaughter would use a value of 0.021 * BW gain.

These should be summed over the number of animals at the different production stages.

TABLE 10.20C
DEFAULT VALUES FOR N_{GAIN} BY GROWTH STAGE

Phase	N_{gain} (kg N kg BW^{-1})
Nursery (4 to 7 kg)	0.031
Nursery (7 to 20 kg)	0.028
Grower (20 to 40 kg)	0.025
Grower (40 to 80 kg)	0.024
Finisher (80 to 120 kg)	0.021

N_{gain} can be calculated for a given BW as $N_{gain} = -0.004 \ln(BW) + 0.0381$ Based on Shields et al. (1983).

For the calculation of the $N_{retention\_frac(T)}$, the daily N retention can be calculated by dividing the result of equation 10.33C by the total number of days in the growth periods to provide a daily N retention in Kg N day^{-1}. The total annual N excretion will be the sum of the N excretion of each cycle calculated in 365 days. Consideration should be taken for periods between production cycles in the calculation of annual values.

In estimating N excretion by growing pigs (Equation 10.33C), the following considerations need to be taken into account:

It should be noted that the approach used for estimating N excretion from growing pigs can be followed for gilts and growing boars that will be used for breeding purposes and for nursery, growing and finishing market pigs.

Example of Tier 2 method for estimating nitrogen excretion for poultry

In broiler production, chicks generally cannot digest and absorb all nutrients, especially in the case of nutritional imbalance or high concentration of nutrients in feed. Thus, the surplus nutrients are broken down, and carbon is used to produce energy whereas nitrogen is excreted in feces (Boonsinchai *et al.* 2016). Different categories of animals (meat or egg chickens) can have quite different N requirements and different N retention rates (Poulsen & Kristensen 1998; Williams 2013; Velthof *et al.* 2015). Thus, when following a Tier 2 approach for estimating nitrogen excretion for poultry, it is a good practice to include N excretion estimations for least the poultry categories listed in Table 10.2

In estimating nitrogen excretion, the nitrogen balance approach is also very useful, for which information in feed intake, feed N content and animal productivity (egg production, weight gain, lengths of production stages) is required. A suitable approach to estimate annual nitrogen excretion by layer type hens is as follows (Poulsen & Kristensen 1998):

EQUATION 10.33D
N RETENTION RATES FOR LAYER TYPE HENS

$$N_{retention} = \left[N_{maintenance} + \left(Egg\ production / 100 \right) \bullet N_{egg} \right]$$

Where:

$N_{retention}$= amount of N retained in bird (kg d^{-1})

$N_{maintenance}$ = N needed for daily maintenance (kg bird^{-1} d^{-1})

Egg production = rate of egg production (%, usually associated with age)

N_{egg} = N content of eggs produced (kg)

TABLE 10.20D
DEFAULT PARAMETERS FOR THE CALCULATION

Production	$N_{maintenance}$ (kg bird^{-1} d^{-1})	N_{egg} (kg egg^{-1})
Commercial	0.000413	0.001
Backyard/freerange	0.00121	0.000824

Data for backyard chickens from Brainer *et al.* (2016), data for commercial from Latshaw and Zhao (2011), Meluzzi *et al.* (2001), Liebert *et al.* (2005). A suitable approach to estimate annual nitrogen excretion by pullets is as follows (Poulsen & Kristensen 1998):

For the calculation of the $N_{retention\_frac(T)}$, the daily N retention can be calculated by dividing the result of equation 10.33B to provide a daily N retention in kg N day^{-1}.

EQUATION 10.33E
ANNUAL N RETENTION RATES FOR PULLETS OR BROILERS

$$N_{retention} = \frac{(BW_{Final} - \mathrm{BW}_{Initial}) \bullet N_{gain}}{production\_period}$$

Where:

$N_{retention}$= amount of N retained in animal (kg^{-1}) day^{-1}

$BW_{Final(i)}$ = Live weight of the animal at the end of the stage (kg)

$BW_{Initial}$ = Live weight of the animal at the beginning of the stage (kg)

N_{gain} = the amount of N (kg) retained per kg BW gain

Production_period = length of time from chick to slaughter

Default value for N per gain = 0.037 Based on data from Xue *et al.* (2016); Malomo *et al.* (2013); and Aletor *et al.* (2001)

For the calculation of the $N_{retention\_frac(T)}$, the daily N retention can be calculated by dividing by the result of equation 10.33B to provide a daily N retention in Kg N day^{-1}. In the calculation of annual N excretion consideration should be taken of sanitation periods occurring between production periods.

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, FracGasMS, and leaching/runoff, FracLeachMS), 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 for single manure systems. Values represent the sum of the loss rates for N 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 air pollutant emission inventory guidebook, Chapter 3B (current version: EEA 2016).

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. A Tier 2 method is also required if manure is managed in multiple 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, if manure is managed in multiple system, emissions from all systems must be considered. For example, values provided for dairy anaerobic lagoon systems should 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, if these systems are associated also with all or a share of the manure managed in dairy anaerobic lagoon systems.

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).

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

	Definition	EF_3 [kg N_2O-	Uncertainty	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, d]	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.	0.010	Factor of 2	Expert judgement based on Pardo *et al.* (2015). Median of N2O emissions from farm-scale collected studies.
Solid storage-Covered/compacted[d]	Similar to solid storage, but the manure pile is a) covered with a plastic sheet to reduce the surface of manure exposed to air and/or b) compacted to increase the density and reduce the free air space within the material.	0.01	Factor of 2	Expert judgement based on Pardo *et al.* (2015). Emissions in the same range than solid storage
Solid storage - Bulking agent addition[d]	Specific materials (bulking agents) are mixed with the manure to provide structural support. This allows the natural aeration of the pile, thus enhancing decomposition. (e.g. sawdust, straw, coffee husks, maize stover)	0.005	Factor of 2	Expert judgement based on Pardo *et al.* (2015). Estimated reduction of 50% N2O emissions due to bulking agent addition
Solid storage - Additives[d]	The addition of specific substances to the pile in order to reduce gaseous emissions. Addition of certain compounds such as attapulgite, dicyandiamide or mature compost have shown to reduce N2O emissions; while phosphogypsum reduce CH4 emissions	0.005	Factor of 2	Expert judgement based on Pardo *et al.* (2015). Estimated reduction of 50% N2O emissions due to additives
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 *et al.* (2003)

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

	Definition		EF_3 [kg N_2O-	Uncertainty	Source[a]
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.
Liquid/Slurry	cover		0.005	Factor of 2	A detailed literature review carried out during the 2019 refinement revealed only few new datasets on the measurement of N_2O emissions from manure stores. These datasets emcompass a large range of N_2O emissions from a 50% reduction to a 100 % increase in N_2O emissions when slurry stores are covered. The 2019 refinement therefore suggest to use the emission factor of crust cover.
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 *et al.* (2003), and Sneath *et al.* (1997).
Anaerobic digester	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.		0.0006	Not applicable	The emission mainly from storage of digestate storage. Judgement of IPCC Expert Group in combination with the following studies: Wang *et al.* (2016), Rodhe *et al.* (2015); Wang *et al.* (2014b); Wang *et al.* (2014a); Li (2016); Amon

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

	Definition		EF_3 [kg N_2O-	Uncertainty	Source[a]
					et al. (2006); Moitzi *et al.* (2007); Clemens *et al.* (2006).
Burned for fuel or as waste	The dung is excreted on fields. The sun dried dung cakes are burned for fuel.		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.		
	Urine N deposited on pasture and paddock		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.		
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.	No mixing	0.01	Factor of 2	Average value based on Moller *et al.* (2000), Sommer and MØLler (2000), Amon *et al.* (1998a); Amon *et al.* (1998b), and Nicks *et al.* (2003).
		Active mixing	0.07	Factor of 2	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.
Composting - In-Vessel[c]	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.		0.006	Factor of 2	Judgement of IPCC Expert Group. Expected to be similar to static piles.
Composting - Static Pile[c] (Forced aeration) [d]	Composting in piles with forced aeration but no mixing.		0.010	Factor of 2	Expert judgement based on Pardo *et al.* (2015). Emissions in the same range than solid storage
Composting - Intensive Windrow[c] (Frequent turning)	Composting in windrows with regular turning for mixing and aeration.		0.005	Factor of 2	Assuming similar range to passive windrow.
Composting- Passive windrow (infrequent turning) [d]	Composting in windrows with infrequent turning for mixing and aeration.		0.005	Factor of 2	Expert judgement based on Pardo *et al.* (2015). Median of N2O emissions from farm-scale collected studies and estimated reduction of 50% due to bulking agent addition
Poultry manure with litter	Similar to deep bedding systems. Typically used for all poultry breeder flocks and for the production of meat type chickens (broilers) and other fowl.		0.001	Factor of 2	Judgement of IPCC Expert Group based on the high loss of ammonia from these systems, which limits the availability of nitrogen for nitrification/denitrification.

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

	Definition		EF_3 [kg N_2O-	Uncertainty	Source[a]
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.		0.001	Factor of 2	Judgement of IPCC Expert Group based on the high loss of ammonia from these systems, which limits the availability of nitrogen for nitrification/denitrification.
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 ***AFRC (1995)*** and 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.

[d] Sources and assumptions to calculate N_2O EF for *Solid storage categories and composting (static pile and passive windrows)* are detailed in Annex 10 B.7.

TABLE 10.21B
MANURE MANAGEMENT N_2O EMISSION FACTORS FOR DEER, REINDEER, RABBITS, AND FUR-BEARING ANIMALS

Livestock	N_2O Range	mean±SD
Deer[a]	0.0206~0.2419	0.08±0.08
Reindeer[b]	NO	NO
Rabbits[c]	0.0012~0.2251	0.07±0.08
Fur-bearing animals (e.g., fox, mink)[b]	0.018~0.146	0.05±0.04
Ostrich	0.0057~0.1962	0.12±0.09

Source: Calculation of IPCC expert group based on country submissions in CRF tables to UNFCCC

10.5.3 Choice of activity data

No refinement in this section

we may want to consider that the "activity data" section could be the proper place to account for additional N input via co-digestates?

10.5.4 Coordination with reporting for N_2O emissions from managed soils

This section is an update

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 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 of reactive nitrogen gases (i.e., NH_3 and NO_x) or through leaching and runoff (both leading to indirect emissions of N2O), direct conversion to N_2O, or losses as inert molecular nitrogen (N2).

Nitrogen in manure is present both as organic nitrogen (Norg) and mineral nitrogen, called 'Total Ammoniacal Nitrogen' (TAN). The sum of Norg and TAN gives the total nitrogen available (Ntot). Volatilization of NH_3 and other forms of gaseous N arise from the mineral fraction of nitrogen in manure, TAN. Organic nitrogen in manure needs first to be converted to TAN before NH_3 volatilization can happen. The EMEP/EEA air pollutant emission inventory Guidebook 2016 (EEA 2016, Chapter 3B) therefore distinguishes the flow of TAN and Norg and the transitions between the two forms in agricultural systems. The values for the volatilization fraction FracGASMS listed in Table 10.24 attempt to account for typical TAN contents in manure for the MMS considered. However, different excretion ratios of TAN vs. total N as a consequence of changes in livestock diets are not reflected. Also, information on the TAN content in manure available for application, N_{MMS_Avb}, is not kept if using Equation 10.34. Farming practices that reduce the escape of NH_3 from MMS but not the amount of TAN available are likely to lead to higher NH_3 volatilization rates once the manure is applied to soils or used for feed, fuel, or for construction purposes.

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. The same applies to additional N input from co-digestates during anaerobic digestion. 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 (EEA 2016). If bedding material comes from crop residues, the amount of nitrogen needs to be considered when calculating N_2O emissions from crop residues from managed soils by accounting for this quantity in $Frac_{Remove(T)}$ in Equation 11.6 of *Chapter 11*. Further codigestates in the production of biogas may include food waste as well as purpose grown crops. Differences in N loss that might occur with crop residue being digested or being returned directly to the fields should be considered in this case.

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

$$N_{MMS_{Avb}} = \sum_{S}\left\{\sum_{(T)}\left[\left[\left(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)}\right) \bullet \left(1-\frac{Frac_{LossMS}}{100}\right)\right] + \left[N_{(T)} \bullet MS_{(T,S)} \bullet N_{beddingMS}\right]\right]\right\} + N_{codigestates}$$

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

$Frac_{LossMS}$ = total fraction of managed manure nitrogen for livestock category *T* that is lost in the manure management system *S*, %. $Frac_{LossMS}$ is calculated according to equation 10.34a

$N_{beddingMS}$ = 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}

$N_{codigestates}$ = amount of nitrogen from co-digestates added to biogas plants such as food wastes or purpose grown crops kg N yr^{-1}

S = manure management system

T = species/category of livestock

EQUATION 10.34B
FRACTION OF TOTAL ANIMAL MANURE N LOST IN MANURE MANAGEMENT SYSTEMS FOR ANIMAL TYPE T

$$\mathbf{FRAC_{LOSSMS} = FRAC_{GASMS} + FRAC_{LEACHSMS} + FRAC_{N2MS} + 100\ EF_{3(S)}}$$

Where:

$Frac_{LossMS}$ = total fraction of managed manure nitrogen for livestock category *T* that is lost in the manure management system *S*, %. $Frac_{LossMS}$ is calculated according to equation 10.34a

$Frac_{GASMS}$ = amount of managed manure nitrogen for livestock category *T* that is lost by volatilisation in the manure management system *S*, % as NH_3 or NO_X (see Table 10.24)

$Frac_{LEACHSMS}$ = amount of managed manure nitrogen for livestock category *T* that is lost in the manure management system *S*, % by leaching or run-off (see Table 10.24)

$Frac_{N2MS}$ = amount of managed manure nitrogen for livestock category *T* that is lost in the manure management system *S*, % as N_2 (see Table 10.23)

$EF_{3(S)}$ = 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*

The amount of managed nitrogen nitrogen that is lost by denitrification to N_2 can be obtained as a ratio of N_2:N_2O emissions. Webb and Misselbrook (2004) reviewed available data and concluded that as first approximation, emissions of N_2 might be 3-times those of N_2O. $Frac_{N2MS}$ can thus calculated according to Equation 34C.

EQUATION 10.34C
ESTIMATION OF FRAC$_{N2MS}$

$$Frac_{N2MS} = R_{N2,N2O} \bullet 100 \bullet EF_{3(S)}$$

Where:

$Frac_{N2MS}$ = amount of managed manure nitrogen for livestock category *T* that is lost in the manure management system *S*, % as N_2 (see Table 10.23)

$EF_{3(S)}$ = 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*

R_{N2_N2O} = Ratio of N_2 : N_2O emissons. The default value of R_{N2_N2O} is 3 kg N_2-N (kg N_2O-N)$^{-1}$

100 = Conversion factor for dimensionless emission factor to loss fraction in percent

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).

As regards $N_{beddingMS}$ a cross check with the categories "Crop residue N, including N-fixing crops and forage/ pasture renewal, returned to soils, (FCR)" (included in the 3D CRF category - volume 11 chapter 11 section 11.2.1.3), "Field Burning of Agricultural Residues" (3F CRF category - volume 4 chapter 5 section 5.2.4 Non-CO2 greenhouse gas emissions from biomass burning) and "Open burning of waste - other: agricultural waste" (5C CRF category - volume 5 chapter 5 section 5.3.2 Amount of waste open-burned), relative to the amount of agricultural residues that is removed for other purposes (i.e. bedding) other than the amount of agricultural residues returned to soils or burnt should be done. See box reported in Crop residues (see comment below regarding crop residues). This is important to eliminate the possibility of double counting.

Nitrogen content of co-digestates should be estimated in accordance with the values used in the sections “Energy” and “Waste”.

Table 10.22 presents default values for nitrogen loss due to volatilisation of NH_3 and NO_x and N leaching of nitrogen from manure management.

Table 10.25 presents default values for total losses of N_2 from manure management systems relative to emissions of N_2O. This ratio is used in combination with Equation 10.41C to calculate default N_2 emision factors. 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.

Countries may wish to develop an alternative approach for better consideration of national circumstances and to reduce the 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. For Tier 2 or Tier 3 approaches it is good practice to account for the TAN fraction in total manure N along the different stages of manure management, storage, and application. Additional details are available in the EMEP/EEA air pollutant emission inventory Guidebook 2016 (EEA 2016, Chapter 3B-3.4 and Annex A1.4).

TABLE 10. 22
DEFAULT VALUES FOR NITROGEN LOSS DUE TO VOLATILISATION OF NH_3 AND NO_X AND LEACHING OF NITROGEN FROM MANURE MANAGEMENT

System	**Applicable System Variation**	**Swine**		**Dairy Cow**		**Poultry**		**Other Cattle**		**Other animals**	
		[1]**$Frac_{Gas\_MS}$**	[2,5]**$Frac_{leach\_MS}$**	**$Frac_{Gas\_MS}$**	[2,5]**$Frac_{leach\_MS}$**	**$Frac_{Gas\_MS}$**	[2,5]**$Frac_{leach\_MS}$**	**$Frac_{Gas\_MS}$**	[2,5]**$Frac_{leach\_MS}$**	**$Frac_{Gas\_MS}$**	[2,5]**$Frac_{leach\_MS}$**
Daily spread		*7%* *(5 – 60)*	0%	**7%** **(5 – 60)**	0%	*7%* *(5 – 60)*	0%	*7%* *(5 – 60)*	0%	*7%* *(5 – 60)*	0%
[7]Solid storage		**45%** **(10 – 65)**	2%	**30%** **(10 – 40)**	2%	**40%** **(12 – 60)**	2 %	**45%** **(10 – 65)**	2 %	**12%** **(5 – 20)**	2 %
[7]Solid storage-Covered/compacted		**22%** **(4-26)**	0%	**14%** **(2-17)**	0 %	**20%** **(4-24)**	0%	**22%** **(3-26)**	0%	**5%** **(0-7)**	0%
[7]Solid storage – Bulking agent addition		**58%** **(11-70)**	2%	**38%** **(6-46)**	2%	**54%** **(10-65)**	2%	**58%** **(8-70)**	2%	**15%** **(6-18)**	2%
[7]Solid storage – Additives		**17%** **(3-21)**	2%	**11%** **(1-14)**	2%	**16%** **(3-20)**	2%	**17%** **(2-21)**	2%	**4%** **(1-5)**	2%
Dry lot		**45%** **(10 – 65)**	3.5%	**30%** **(20 – 50))**	3.5%	NA	3.5%	**30%** **(20 – 50)**	3.5%	*30%* *(20 – 50)*	3.5%
Liquid/Slurry	With natural crust cover	30% (9 – 36)	0	**30%** **(9 – 36)**	0	NO	0	**30%** **(9 – 36)**	0	*9%*	0
	Without natural crust cover	**48%** **(15 – 60)**	0	**48%** **(15 – 60)**	0	*40%* *(25 – 75)*	0	**48%** **(15 – 60**	0	*15%*	0
	With cover	**10%** **(3 – 12)**	0	**10%** **(3 – 12)**	0	8% (5-15)	0	**10%** **(3 – 12)**	0	*3%*	0
Uncovered anaerobic lagoon		**40%** **(25 – 75)**	0	**35%** **(20 – 80)**	0	**40%** **(25 – 75)**	0	*35%* *(20 – 80)*	*0*	*35%* *(20 – 80)*	0

Pit storage below animal confinements		**25% (15 – 30)**	0	**28% (10 – 40)**	0	***28% (10 – 40)***	0	***25% (15 – 30)***	0	***25% (15 – 30)***	0
[3]Anaerobic digester		5-50%[6]	0	5-50%	0	5-50%	0	5-50%	0	5-50%	0
Burned for fuel or as waste		NA									
Cattle and swine deep bedding		**40% (10 – 60)**	0-3.5%	**25% (10 – 30)**	0-3.5%	**30% (20 – 40**)	0-3.5%	**25% (10 – 30)**	0- 3.5%	***40% (10 – 60)***	0-3.5%
[3]Composting – In-Vessel[c]		*60% (12-65)*	*0*	*45% (7-54)*	*0*	*60% (12-65)*	*0*	*60% (12-65)*	*0*	*18% (4-21)*	*0*
[7]Composting - Static Pile[c]		**65% (14-70)**	6%	**50% (7-60)**	6%	**65% (14-70)**	6%	**65% (14-70)**	6%	**20% (5-24)**	6%
[3]Composting – Intensive Windrow[c]		*65% (14-70)*	*6%*	*50% (7-60)*	*6%*	*65% (14-70)*	*6%*	*65% (14-70)*	*6%*	*20% (5-24)*	*6%*
[7]Composting – Passive Windrow[c]		**60% (12-65)**	4%	**45% (7-54)**	4%	**60% (12-65)**	4%	**60% (12-65)**	4%	**18% (4-21)**	4%
Poultry manure with litter		NA				**40% (10 – 60)**	0	NA			
Poultry manure without litter		NA				**48% (15 – 60)**	0	NA			
[3]Aerobic treatment	Natural aeration systems	no data[7]	0	no data[7]	0	no data	0	no data	0	no data	0
	Forced aeration systems	85% (27 – 100)	0	85% (27 – 100)	0	no data	0	85% (27 – 100)	0	27%	0

Source: The values are mainly from 2006 guidelines but other sources and analyses re discussed in Annex B.7.Values in italics are not derived specifically from literature but are taken from the most likely surrogate among the existing values and are for that reason prone to greater uncertainty. These values may be further revised in the Final Draft.

1. N loss due to volatilisation of NH_3+NO_x fraction of total N excreted

2. N loss due to leaching, fraction of total N excreted

3. Nitrogen losses from digestate storage strongly depend on the digestate composition and on the storage cover. Digestate with a low dry matter content and no cover can loose up to 50 % of nitrogen. The lower range of 5% losses is valid for digestate with a high dry matter content and a cover.

4. Uncertain range is 0 to 7%. leaching values are dependant on annual rainfall. Country-specific data should be developed if leaching is observed to be a significant source based and default values and in humid climates should use the upper bound.

5. Leaching is only included in the case of uncovered manure without confinement of runoff in which N is lost to the environment and therefore lost from the overall reactive N balance.

6. No data indicates that no literature values were found, nor was there adequate certainty in providing a surrogate value. Further literature reviews will be carried out for the final draft.

7 Sources and assumptions to calculate NH_3 and leaching/run-off EF for *Solid storage categories and composting (static pile and passive windrows)* are detailed in Annex 10 B.7.

TABLE 10.23 DEFAULT VALUE FOR MOLECULAR NITROGEN (N_2) LOSS FROM MANURE MANAGEMENT			
Factor	**Unit**	**Value**	**Range**
R_{N2_N2O}	3 kg N_2-N (kg N_2O-N)$^{-1}$	3[1]	1-10

[1] Webb and Misselbrook (2004)

10.5.5 Uncertainty assessment

No refinement in this section

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

This section doesn't contain a refinement.

It does contain new guidance in a new subsection Consistency of nitrogen flows

A complete inventory should estimate N_2O emissions from all systems of manure management for all livestock species/categories. Additional N input from organic residues and/or energy crops used for co-digestion in biogas plants must also be considered. Countries are encouraged to use manure management system definitions that are consistent with those presented in Table 10.24. 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 10.24. 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* animal if deposited by grazing aninmals, or under *manure management* if collected in housed systems.

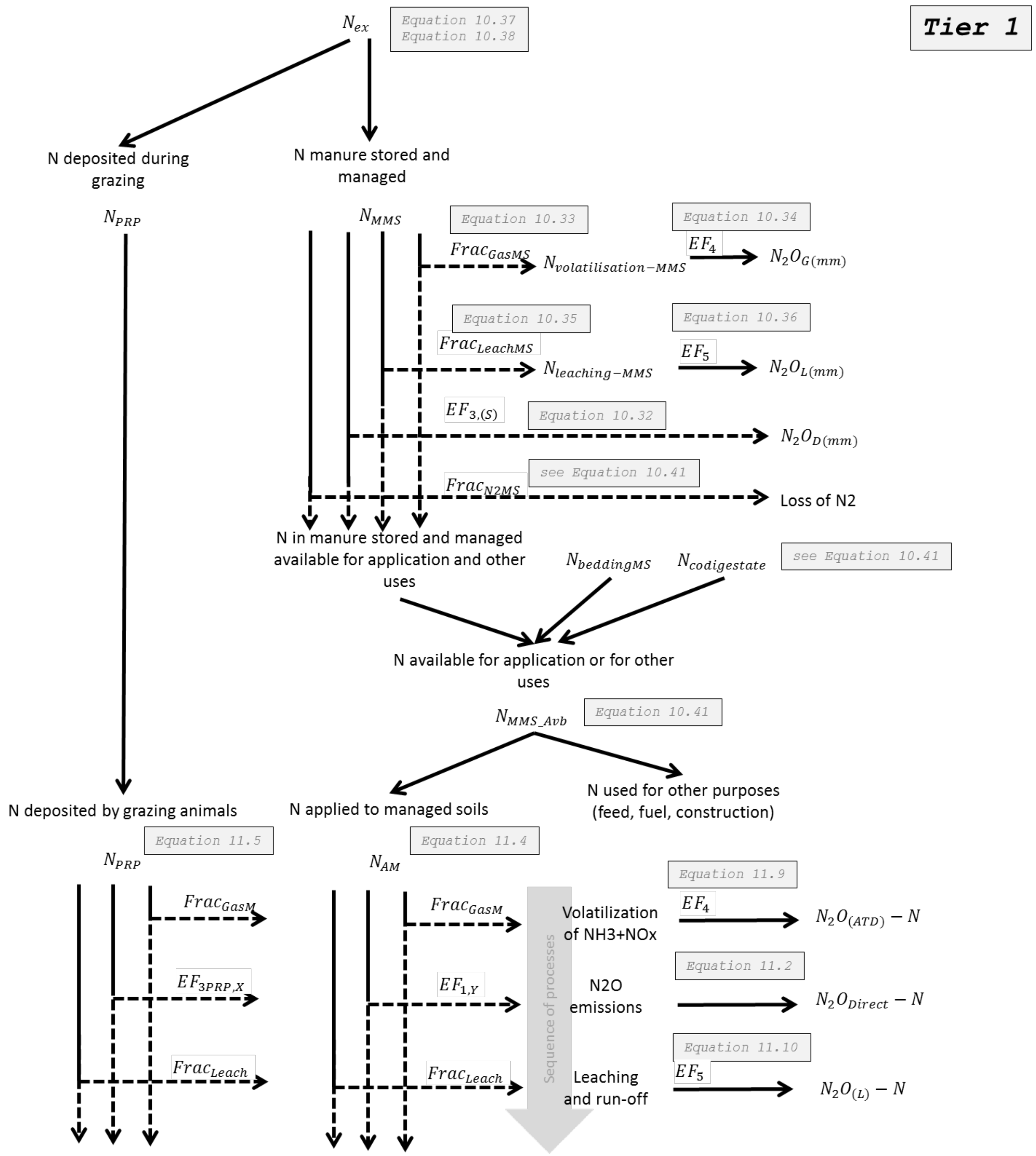
New sub-section:

Consistency of nitrogen flows

As discussed in Section 10.5.4, most of the manure excreted by livestock is finally applied to land or deposited to land by grazing animals, causing direct and indirect N_2O emissions from managed soils. On its way from the animal to uptake by crops or the release of N_2O, losses of nitrogen happen at all stages and in different forms. With anaerobic digestion, additional N might enter the system through co-digestates (e.g. organic residues, energy crops). The equations given in Chapters 10 and 11 follow a nitrogen balance approach, but are not capturing all effects on direct and indirect N_2O emissions that might occur as a consequence of 'upstream' changes of nitrogen flow, such as manure covers, changes in animal feeding, or nitrogen application technique, some of which are discussed in Section 10.5.4. It is also important to consider total N_2O emissions (see Equation 10.A4-1) when making a key source assessment.

The inventory agency should consult with experts to make sure that any potential effects on N_2O emissions are reflected in the total N_2O emission estimates. Annex 10.A3 lists a set of equations derived from relevant equations in Chapter 10 and 11, allowing the calculation of all direct and indirect N_2O emissions per livestock species/category. These equations can help identifying emissions that might become inaccurate when national methodologies for upstream flows are used. For example, equation 10. A3-7 and equations 11.2-11.4 show that direct N_2O emissions from soils depend on the amount of manure N available for application, not considering any NH_3 losses that might change the amount of N available for N_2O formation. So any application technique that reduces or increase losses of NH_3 and increase or decreases the availability of N that can be transformed to N_2O must be carefully evaluated (see also Chapter 11, Sections 11.2.1.1 and 11.2.2.1). Possibly, a correction factor needs to be introduced that is consistent with the national method for NH_3 emissions. An illustration of N flows through animal and crop production systems is given in Figure 10.5. The figure follows the flow of nitrogen, starting from excretion of nitrogen by animals through livestock and crop production systems down direct or indirect emissions of N_2O. For each flow shown in Figure 10.5, reference is made to the respective equation in *Chapter 10 EMISSIONS FROM LIVESTOCK AND MANURE MANAGEMENT* and *Chapter 11 N_2O EMISSIONS FROM MANAGED SOILS, AND CO_2 EMISSIONS FROM LIME AND UREA APPLICATION.* Losses to the environment are shown with broken arrows and indicate the emission factor or loss fraction to be used. Nitrogen input from bedding material and co-digestates enter the system and become part of the N available for application or for other uses.

Figure 10. 5 Processes leading to the emission of gaseous N species from manure (*New Figure)*



Symbols as defined under the Equations in Chapter 10 and 11 and in Annex 3 of Chapter 10. In this graph all flows denoted with *N* are averaged annual N flows per head of livestock species/category [kg N animal^{-1} yr^{-1}]; symbols denoted with Frac are fractions in [kg N (kg N)$^{-1}$]; symbols denoted with EF are N_2O emission factors in [kg N_2O -N (kg N)$^{-1}$]. X: different EF_3 are used for cattle, pig and poultry (X=CPP) and for sheep and other animals (X=SO). Y: different EF_1 are used for flooded rice fields (Y=FR) and for other fields (no index Y used).

Broken arrows indicate flows that are split into an emission pathway and a flow of N in the agricultural system.

Note that for N deposited by grazing animals or N applied to managed soils, the flow of N is a sequence of processes with first volatilization of NH$_3$+NOx and only thereafter emissions of N_2O and N leaching. This is not reflected in the equations proposed for Tier 1 methodology.

10.5.7 Use of worksheets

No refinement

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Section 10.2 Livestock Population and Feed Characterisation

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Section 10.4 Methane Emissions from Manure Management

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