CHAPTER 10

EMISSIONS FROM LIVESTOCK AND MANURE MANAGEMENT

Authors:

Olga Gavrilova (Estonia), Adrian Leip (EU), Hongmin Dong (China), James Douglas MacDonald (Canada), Carlos Alfredo Gomez Bravo (Peru), Barbara Amon (Germany), Rolando Barahona Rosales (Honduras), Agustin del Prado (Spain), Magda Aparecida de Lima (Brazil), Walter Oyhantçabal (Uruguay), Tony John van der Weerden (New Zealand), Yeni Widiawati (Indonesia)

Contributing Authors:

Andre Bannink (Netherlands), Karen Beauchemin (Canada), Harry Clark (New Zealand), April Leytem (USA), Ermias Kebreab (USA), Ngwa Martin Ngwabie (Cameroon), Carolyn Imede Opio (Uganda), Andrew VanderZaag (Canada), Theunis Valentijn Vellinga (Netherlands)

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10. EMISSIONS FROM LIVESTOCK AND MANURE MANAGEMENT

Users are expected to go to Mapping Tables in Annex 1 Volume 4 (AFOLU), before reading this chapter. This is required to correctly understand both the refinements made and how the elements in this chapter relate to the corresponding chapter in the 2006 IPCC Guidelines.

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. Carbon dioxide (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 methane (CH_4) and for this reason CH_4 requires separate consideration.

Livestock production can result in 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 CH_4, 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

No refinement.

10.2.2 Choice of method

TIER 1: BASIC CHARACTERISATION FOR LIVESTOCK POPULATIONS

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

Livestock species : A complete list of all livestock populations by species 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 species are relevant to the country. Populations by species can also be further subdivided by category. Category refers to classification inside a species by different relevant attributes as sex, age or productive purpose in a relevant production system in any given country (e.g. in the case of cattle: mature males and females, replacement heifers, calves, etc.). 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, FAOSTAT and other FAO statistics, 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. When population by species is subdivided by categories it is important to fully document any adjustments done in the population to match the categories used in the inventory compilation.

Compilers could consider to communicate/share the annual population data needs with the national statistical agency and/or the other sources from which the data was obtained, so this sources are better aware of the needs of inventory compilers. In addition, national statistical agencies and agencies responsible for inventory compilation can work closely together to ensure that official statistics better meet the needs of the inventory compilers.

Annual average populations are referred to as the number of head of livestock species per category within a given country ($N_{(T)}$). This can be 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 number of head of a given livestock species in the country ($N_{(T)}$) may be as simple as obtaining data related to one-time animal inventory data. However, estimating $N_{(T)}$ 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 $N_{(T)}$.

EQUATION 10.1 (UPDATED)
ANNUAL AVERAGE POPULATION

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

Where:

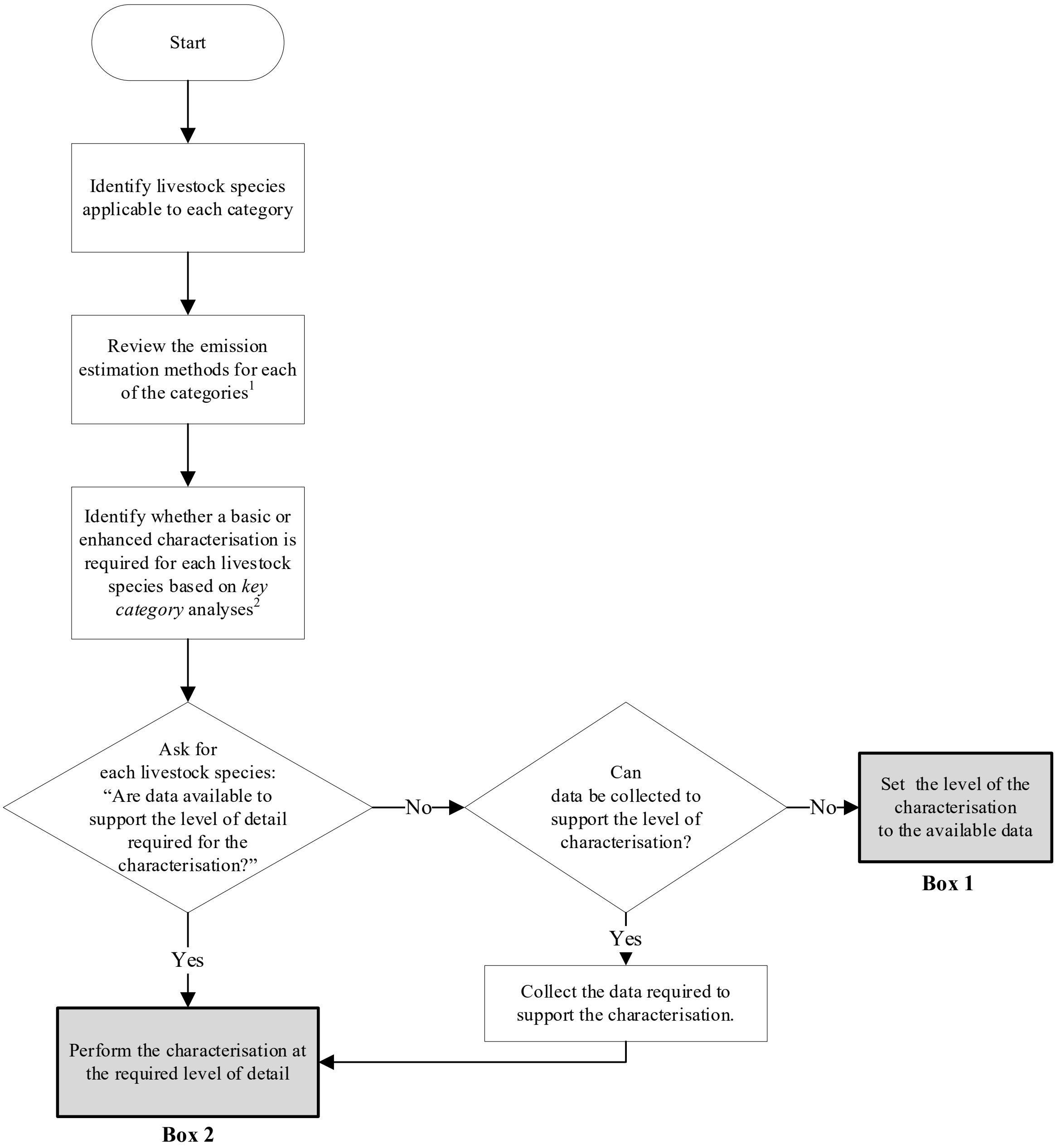
N_T = the number of head of livestock species / category *T* in the country (equivalent to annual average population)

NAPA = number of animals produced annually

Broiler chickens are typically grown approximately 60 days before slaughter. Estimating $N_{(T)}$ 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:

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

Figure 10.1 Decision tree for livestock population characterisation



Note:

1: These categories include: CH_4 from Enteric Fermentation, CH_4 from Manure Management, N_2O 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 systems (Tier 1a)

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 markets or may simply have dual agricultural systems, with coexistence of low and high productivity systems clearly identified. In these cases inventory compilers may wish to use the Tier 1a approach in which they are able to better track the transitions and changes in the productivity of their agricultural systems and related emissions over time. Tier 1a emission factors (on a per head basis) have been developed for use with basic population estimates separated by low and high productivity systems according to the definitions below.

In this case animal populations by species may be divided by productivity systems. For each animal species high and low productivity systems may be defined according to characteristics such as: feedbase, genetics, purpose (draft, cultural reasons, self-consumption, market), production objectives (e.g. milk, meat, eggs), and level of inputs and outputs.

Definitions of High and Low Productivity Systems

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 cows (first lactation and beyond) that are producing milk in commercial quantities for consumption. This definition corresponds to the dairy cow population reported in FAO, IDF, IFCN (2014). Dairy cow population should not be confused with multi-purpose cows that may be used for more than one production purpose milk, meat or draft.

In some countries the dairy cow population is comprised of two well-defined segments:

High-productivity systems are based on high-yielding dairy cows that are concentrated in confinement production systems or grazing on high quality pastures with supplements. The farms are 100 percent market oriented for commercial milk production, for national markets and/or export; Purebred or crossbred cattle are genetically improved through selective breeding for milk production (FAO, IDF, IFCN 2014). Indicative levels of high milk productivity by cow corresponding to a given region are included in Table 10.11 to guide the selection of the emission factors.

Low productivity systems are based on low-yielding dairy cows, grazing non-improved pastures, and using locally produced roughage (e.g. crop residues), and agro-industrial by-products. Local breeds or crossbred cows are bred locally, without intensive selection for milk productivity. Milk production is mostly for local market and local consumption (FAO, IDF, IFCN. 2014). Indicative levels of low milk productivity by cow corresponding to a given region are included in Table 10.11 to guide the selection of the emission factors.

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

Other cattle:

High-productivity systems are based on animal feeding systems using forage (e.g. high-quality grass) and concentrates in confinement production systems or grazing with supplements or on improved pastures, producing high rates of daily weight gain. Animals can be purebred or crossbred and are genetically improved through selective breeding for improved commercial meat production. Growing cattle may be finished young in "intensive grazing with supplements" or feedlot systems, and meat is produced for national markets and/or export (FAO, IDF, IFCN 2014).

Low productivity systems are based on animal feeding systems where locally produced roughage (e.g. crop residues) or low quality rangelands represent the major source of feed utilized, producing low rates of daily weight gain. Animals can be represented by local breeds or may be crossbred and can also be used for multiple purposes such as draft, meat and milk for self consumption and markets (FAO, IDF, IFCN 2014).

Other livestock species:

High-productivity systems, 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 improved through breeding practices for commercial production. The high-productivity systems are common in swine, poultry, goats and sheep production (MacLeod *et al.* 2017).

Low productivity systems which are mainly driven by local market or by self-consumption, with low capital input requirements and low level of overall herd (fowl) performance typically using large areas for production or backyards. 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 low-productivity systems are common in swine, poultry, goats and sheep production (MacLeod *et al.* 2017).

International statistics sources for activity data, parameters and tools related to animal population

FAO provides international statistical information for livestock characterization, including population and production. Relevant sources are: FAOSTAT Production database and FAO World Census of Agriculture 2020. Additionally, FAO provides a free access e-learning course to support developing countries in the preparation of the national GHG inventory for the agriculture sector. FAO also provides tools that may be useful for inventory compilers in the agriculture sector as the FAOSTAT Emissions Analysis Tools, to identify data gaps and perform QA/QC analysis. Another tool is the Global Livestock Environmental Accounting Model (GLEAM), which is a GIS-based model for livestock production activities and related resource flows in all countries. The FAO-IPCC-IFAD workshop report (IPCC, 2015), identifies the list of all FAOSTAT and other FAO data sources in support of National Inventory compilation in the AFOLU sector.

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 (UPDATED)
Representative livestock categories[1,2]

Main categories	**Production categories Tier 1a**	**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:
		• Bulloks 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 Sheep	High productivity systems	• Breeding ewes for production of offspring and wool production
		• Milking ewes where commercial milk production is the primary purpose
		• Other Mature Sheep (> 1 year)
	Low productivity systems	• Breeding ewes for production of offspring and wool production
		• Other Mature Sheep (> 1 year)
Growing Sheep (lambs)	High productivity systems	• Intact Males, Castrates and Females, concentrate-fed.
	Low productivity systems	• Castrates and Females, grass-fed.

TABLE 10.1 (UPDATED) (CONTINUED)
Representative livestock categories[1,2]

Main categories	Production categories Tier 1a	Subcategories
Goats	High productivity systems	• Dairy Does
		• Mature does
		• Yearlings
		• Bucks
		• Kids (<1 yr)
	Low productivity systems	• Mature does
		• Yearlings
		• Bucks
		• Kids (<1 yr)
Mature Swine	High Productivity Systems	• Sows in gestation
		• 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
		• Growing/Finishing
		• Gilts that will be used for breeding purposes
		• Growing boars that will be used for breeding purposes
	Low Productivity Systems	• Growing / fattening swine
		• Free-range growing swine
		• Gilts/boars that 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

TABLE 10.1 (UPDATED) (CONTINUED)
Representative livestock categories[1,2]

Main categories	Production categories Tier 1a	Subcategories
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.

The livestock classification that is chosen should be consistent for all emission sources, enteric and manure management methane and N_2O from manure management. 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 (Y_m) percentage of feed energy converted to methane;

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

- Weight (kg);
- Average weight gain per day (kg)[1];
- Feeding situation: confined, grazing, pasture conditions;
- Average 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[2];
- Wool growth;
- Number of offspring;
- Digestibility of feed, expressed as the percentage of digestible energy in feed gross energy (DE, percent);
- Crude protein in diet (CP, percent);

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

[2] This is only relevant for mature females.

- Neutral Detergent Fibre (NDF, % DMI), proportion of feed composed of insoluble fibres, hemicellulose, cellulose, lignin and some protein fractions.

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 percent 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, sheep and goats. 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.

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. Slaughter weights can be utilized in live weight estimations if slaughter ages, dressing percentages and growth curves are also available.

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. Mature weights of bulls may be 1.5 times higher than cows in the same genotype (Doren *et al.* 1989).

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, sheep and goats. For poultry and swine, the feeding situation is assumed to be under confinement conditions and consequently the activity coefficient (C_a) is assumed to be zero as under these conditions very little energy is expended in acquiring feed. Activity coefficients have not been developed for free-ranging swine or poultry, but in most instances these livestock subcategories are likely to represent a small proportion of the national inventory.

Mean winter temperature (ºC): Detailed feed intake models consider ambient temperature, wind speed, hair and tissue insulation and the heat of fermentation (NRC, 2001; AAC, 1990) and are likely more appropriate in Tier 3 applications. A more general relationship adapted from North America data suggest adjusting the Cf_i of Equation 10.3 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 percent in northern North America. This increase in feed use for maintenance leads to 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, Equation 10.2 may not be applicable for adapted animals, or for those protected by wind-breaks or shelter during cold weather. The equation should be applied to adjust the annual Cf_i for unsheltered animals during the period in which they are first exposed to sub-zero (ºC) temperatures, prior to their acclimation (a period of one to two months depending on the region).

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 (percent): Average fat content of milk is required for lactating cows, buffalo, sheep and goats producing milk for human consumption.

Protein content (percent): 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 for 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 and to the development of an active rumen, calves do not emit methane. Since calves pre-weaning is a livestock subcategory, it will in any case be necessary for a country to determine the weaning age and the diet composition pre-weaning to choose the appropriate emission factor.

Feed digestibility (DE): The portion of gross energy (GE) in the feed not excreted in the faeces is known as digestible energy expressed as a percentage (percent). 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 percent of GE intake that will be excreted as faeces. Typical digestibility (DE) values for a range of livestock classes and diet types are presented in Table 10.2 as a guideline. The values have been refined compared to the *2006 IPCC Guidelines*, based on more recent information (Table 10.2). For ruminants, common ranges of feed digestibility are 45-55 percent for crop by-products and range lands[3]; 55-80 percent for managed pastures, well preserved forages, crop by-products and grain supplemented forage-based diets; and 72-85 percent for grain-based diets fed

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[3] Rangelands are defined as land primarily covered by natural grasslands, savannas, woodlands (not meeting the definition of Forest Land) and shrublands, including introduced plant species that are naturalised (Grice *et al*. 2008).

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 Section 10.3).

A low digestibility of 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 change of 10 percent in DE will be magnified to change in 12 to 20 percent when estimating methane emissions and even more (20 to 45 percent) 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 Section 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 DE 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, percent) – 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 percent is required for the calculation of N excretion using a Tier 2 method.

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 (UPDATED)
REPRESENTATIVE FEED DIGESTIBILITY FOR VARIOUS LIVESTOCK CATEGORIES

Main categories	Class	Digestibility (DE as percent)
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 which is 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, sheep and goats. 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 (UPDATED)
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: (NE_m) is the net energy required for maintenance, which is the amount of energy needed to keep the animal in equilibrium where body energy is neither gained nor lost (Jurgens 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

TABLE 10.4 (UPDATED)
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 than non lactating females
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).

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

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

$$NE_a = C_a \bullet NE_m$$

Where:

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

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

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

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

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

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 10.5 (UPDATED)
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 individually, mature females, mature males and steers) in moderate body condition[4], kg

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

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[4] Since statistical offices may collect and report data on highly disaggregated number of cattle population (e.g., bovines less than one year old or bovines aged under 8 months, cattle aged between one and two years old), hence, this parameter (i.e., mature weight) may refer to target weight related to stage of growth. Herewith, the number of days needed for animals to reach from the beginning of growing stage to target weight of this growing stage should be taken into consideration.

EQUATION 10.7
NET ENERGY FOR GROWTH (FOR SHEEP AND GOATS) (UPDATED)

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

Where:

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

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

BW_i = the live bodyweight at weaning, kg

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

a, b = constants as described in Table 10.6.

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

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

TABLE 10.6 (UPDATED)
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)	5.0	0.33

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 percent) (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_1 = net energy for lactation, MJ day^{-1}

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

Fat = fat content of milk, percent 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 10.10) is used when the amount of milk produced is not known. Generally, milk production is known for ewes kept for commercial milk production, but it is not known for ewes that suckle their young to weaning. With a known amount of milk production, the total annual milk production is divided by 365 days to estimate the average daily milk production in kg/day (Equation 10.9). When milk production is not known, AFRC (1990) indicates that for a single birth, the milk yield is about 5 times the weight gain of the lamb. For multiple births, the total annual milk production can be estimated as five times the combined weight gain of all lambs birthed by a single ewe. The daily average milk production is estimated by dividing the resulting estimate by 365 days as shown in Equation 10.10.

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

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

Where:

NE_1 = 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.

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_1 = net energy for lactation, MJ day^{-1}

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

EV_{milk} = the energy required to produce 1 kg of milk, MJ kg^{-1}. A default 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 percent and 3.8 percent by weight for sheep and goats, respectively. Milk fat can vary greatly among breeds. Compilers are encouraged to use country-specific milk fat content to derive EV_{milk} when available

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

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

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

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).

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

For fibre-producing sheep NE_{wool} can be estimated that 0.25 MJ day^{-1} is retained in the fibre (AFRC 1993; AFRC 1995). For fibre-producing goats NE_{wool} can be estimated that 0.25 and 0.08 MJ/day for angora and cashmere breeds (AFRC 1993; AFRC 1995), respectively.

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

EQUATION 10.13 (UPDATED)
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 (UPDATED)
CONSTANTS FOR USE IN CALCULATING NE_P 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 percent of the mature females in the animal category give birth in a year, then 80 percent 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

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

Where:

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

DE = digestibility of feed expressed as a fraction of gross energy (digestible energy/gross energy*100, i.e. DE%)

***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

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

Where:

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

DE = digestibility of feed expressed as a fraction of gross energy (digestible energy/gross energy*100, i.e. DE%)

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, buffalo, sheep and goats 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 (UPDATED)
GROSS ENERGY FOR CATTLE/BUFFALO, SHEEP AND GOATS

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

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}

DE = digestibility of feed expressed as a fraction of gross energy (digestible energy/gross energy, i.e. DE%/100)

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 percent to 3 percent of the body weight of the mature or growing animals. In high producing milk cows, intakes may exceed 4 percent 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 digestibility values (DE): It is also possible to predict dry matter intake for mature and growing cattle based on body weight of the animal, and either the dietary net energy of maintenance concentration of the feed NE_{mf} (MJ kg^{-1} DM) (National Academies of Sciences, Engineering and Medicine 2016) or DE, and for lactating dairy cows, fat corrected milk production. Dietary NE_{mf} 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 10.8a. 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 (NEW)
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 10.8a, MJ kg^{-1}

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

EQUATION 10.18 (NEW)
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 10.8a, MJ kg^{-1} DM^{-1}

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

EQUATION 10.18A (UPDATED)
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, Engineering and Medicine 2016)

TABLE 10.8 (NEW)
DMI REQUIRED BY MATURE NON DAIRY COWS BASED ON FORAGE QUALITY

Forage type	Digestibility (DE, %)	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 10.18B (UPDATED)
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 percent * [(0.4324 * kg of milk) + (16.216 * kg of fat)].

Equations 10.17, 10.18, 10.18A and 10.18B and values in Table 10.8 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 in the case that countries do not have the data required to carry out a full estimate of gross energy use for their catle herd, these equations could be used to independently predict DMI from BW, diet quality (NE_{mf} or DE percent) and milk production. In contrast, the main Tier 2 method predicts DMI based on how much feed must be consumed to meet estimated energy 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. While the Tier 2 estimate of gross energy is the preferred method, 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 percent to 3 percent of the bodyweight of the mature or growing animals and up to 4 percent for high yielding lactating dairy cattle.

TABLE 10.8A (UPDATED)
EXAMPLES OF NE_{MF} CONTENT OF TYPICAL DIETS FED TO CATTLE FOR ESTIMATION OF DRY MATTER INTAKE IN EQUATIONS 10.17 AND 10.18

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_{mf} can also be estimated using the equation: NE_{mf} = REM * 18.45 * DE%/100

10.2.3 Uncertainty assessment

No refinement.

10.2.4 Characterisation for livestock without species: Specific emission estimation methods

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

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

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

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

Approximate emissions factor = $[(\text{wapiti weight}) / (\text{deer weight})]^{0.75}$ * deer emissions factor

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

10.3 METHANE EMISSIONS FROM ENTERIC FERMENTATION

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the bloodstream.

The amount of methane 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).

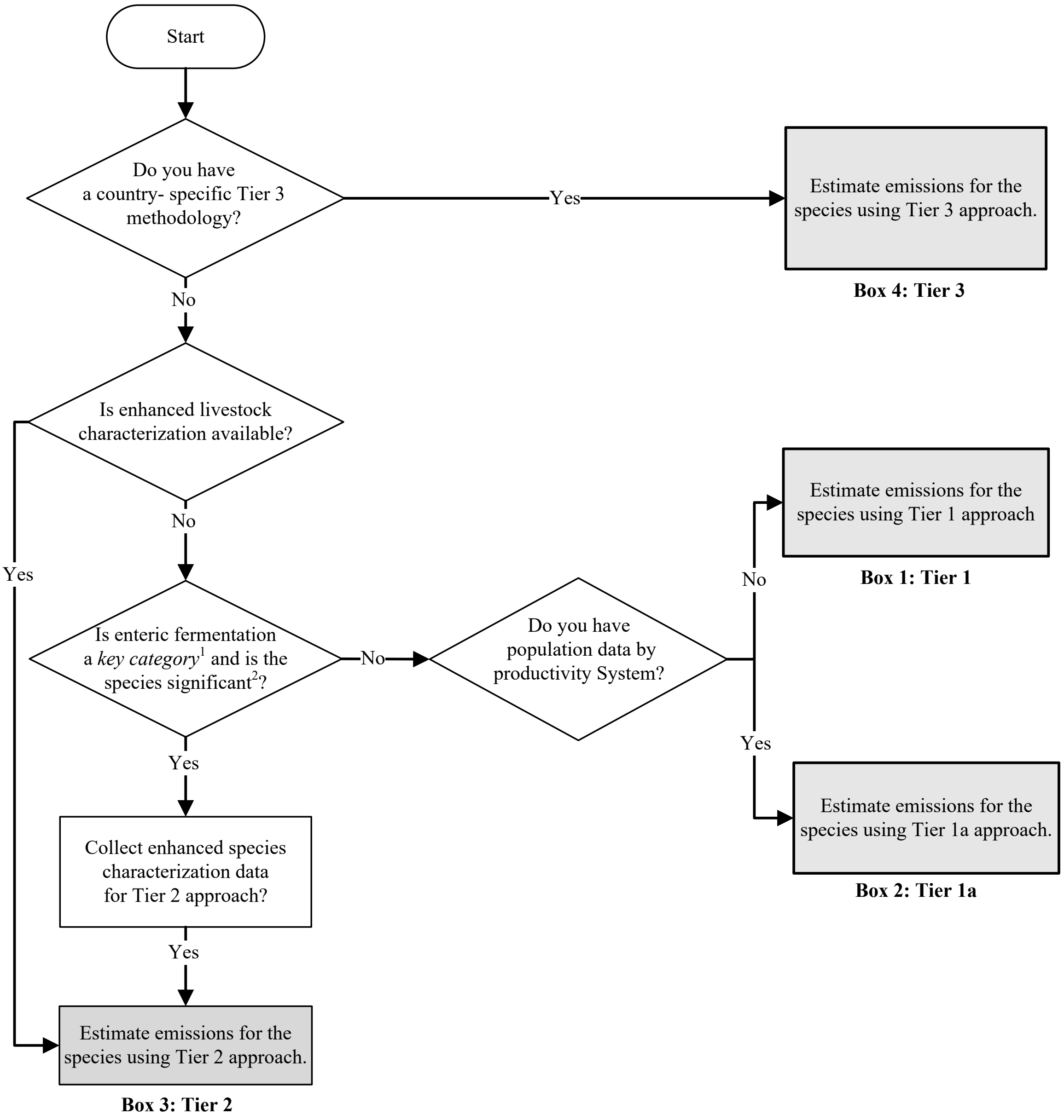
To reflect the variation in emission rates among animal species, the population of animals should be divided into subgroups, and an emission rate per animal is estimated for each subgroup. Types of population subgroups are provided in Section 10.2 (Livestock and Feed Characterisation). The amount of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

Figure 10.2 (Updated) Decision Tree for CH_4 Emissions from Enteric Fermentation



Note:

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

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

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

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

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

Tier 1

A simplified approach that relies on default emission factors established in these guidelines that were either drawn from the literature or calculated using regional data taken from the literature and derived using the Tier 2 method.

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 1a

An advanced Tier 1 method, applicable in particular to countries that have 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 populations of high and low productivity animals and therefore track change in their emissions related to improved productivity.

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.1.

TABLE 10.9 (UPDATED)
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, Ostrich)	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 and buffalo. As shown in the table, emission factors for sheep, goats 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 (as related to animal size) and feed characteristic assumptions. Table 10.11 presents the enteric fermentation emission factors for cattle and buffaloes, accordingly. A range of emission factors is shown for typical regional conditions.

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 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 method, 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 takes into account changes in the number of animals in a country.

To select emission factors from Tables 10.10 and 10.11 identify the region most applicable to the country being evaluated. Scrutinise the tabulations in Annex 10A.1 to ensure that the underlying animal characteristics such as weight, growth rate and milk production used to develop the emission factors are similar to the conditions in the country. The data collected on the average annual milk production by dairy cows should be used to help select a dairy cow emission factor. If necessary, interpolate between dairy cow emission factors shown in the table using the data collected on average annual milk production per head.

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

Table 10.10 (Updated)[2,3]

Enteric fermentation emission factors for Tier 1 method (kg CH_4 head^{-1} yr^{-1})

Livestock	High Productivity Systems[1]	Low Productivity Systems	Liveweight[7]
Sheep	9	5	65 kg – high productivity systems 45 kg – low productivity systems
Swine[6]	1.5	1	72 kg - high productivity systems 52 kg - low productivity systems
Goats[5]	9	5	50 kg – high productivity systems 28 kg – low productivity systems
Horses	18		550 kg
Camels	46		570 kg
Mules and Asses	10		245 kg
Deer	20		120 kg
Ostrich[4]	5		120 kg
Poultry	Insufficient data for calculation		
Llamas and Alpacas	8		65 kg
Other (e.g., bison)	To be determined		

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

Sources:

Emission factors: camels from Gibbs & Johnson (1993); Alpacas from Pinares-Patino *et al*. (2003); Deer from Clark *et al*. (2003); Sheep (High productivity systems) derived from Swainson *et al*. (2016). Sources and assumptions to calculate goats EFs are detailed in Annex 10B.3. Emission factors for other livestock from Crutzen *et al*. (1986),

[1] For the application of the simple Tier 1, for all regions other than North America, Europe and Oceania the Tier 1 default values are the low productivity EFs.

[2] 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.

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

[4] CH_4 EF for ostrich was calculated based on Frei *et al*. (2015) and Danish NIR (Nielsen *et al*. 2018).

[5] Sources and assumptions to adjust weight of goats for low- and high-productivity systems are detailed in Annex 10B.3.

[6] The values of swine weight for low and high productivity systems were obtained from FAO GLEAM databases (FAO 2017). More detailed data on swine weight are reported in Annex 10A.2 (in Table 10A.5). Crutzen *et al*. (1986) did not report weights for swine. Regional Tier 2 calculations for swine have been carried out by the FAO GLEAM research group, countries could consult these values for consistency with their production systems for refinement to their emission factors.

[7] If a country-specific liveweight of animal category is different from those reported in Table 10.10, an inventory-compiler may use the approach presented in section 10.2.4 of the current chapter.

It is recommended to continue to use Tier 1 emission factor uncertainty ranges as defined in Section 10.3.4 of the *2006 IPCC Guidelines*.

Step 3: Total emission

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

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

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

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 for use in advanced Tier 1a – omitted if using Tier 1 approach

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

$$Total\ CH_{4\ Enteric} = \sum_{i,P} E_{i,P}$$

Where:

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

$E_{i,P}$ = is the emissions for the i^{th} livestock categories and subcategories based on production systems (P)

Tier 1 method entails multiplying the total number of livestock population and CH_4 emission factor for each category of livestock (Table 10.10 or Table 10.11). Tier 1a method relies on number of livestock population in each productivity system (i.e., low-productivity systems and high-productivity systems) and CH_4 emission factor for each category of livestock developed per head of animal kept in the specified productivity system (Table 10.10 or Table 10.11).

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

Regional characteristics[8]	Animal category	Tier 1 and Tier 1a Emission Factor[2,3] (kg CH_4 $head^{-1}$ yr^{-1})	Comments[7]
North America			
Cattle: Highly productive commercialised dairy sector feeding high quality forage and grain. Separate beef cow herd, primarily grazing with feed supplements seasonally. Fast-growing beef steers/heifers finished in feedlots on grain. Dairy cows are a small part of the population. There are no buffalo herds, but American bison may be raised.	**Dairy Cattle**	138	Average milk production of 10,250 kg $head^{-1}$ yr^{-1}.
	Other cattle	64	Includes mature males, mature females, calves, growing steers/heifers, and feedlot cattle.
Western Europe			
Cattle: Highly productive commercialised dairy sector feeding high quality forage and grain. Dairy cows also used for beef calf production. Separated beef cow herd. Minor amount of feedlot feeding with grains.	**Dairy Cattle**	126	Average milk production of 7,410 kg $head^{-1}$ yr^{-1}.
	Other cattle	52	Includes mature males, calves, and growing steers/heifers.
Buffalo: 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**	78	Includes mature females, mature males, growing animals and calves.
Eastern Europe			
Cattle: Commercialised dairy sector feeding based on forages and grains. Separate beef cow herd, primarily grazing. Minor amount of feedlot feeding with grains.	**Dairy cattle**	93	Average milk production of 4,000 kg $head^{-1}$ yr^{-1}.
	Other cattle	58	Includes mature males, mature females, growing and replacement animals, and calves.
Buffalo: 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**	68	Includes mature females, mature males, growing animals and calves.
Oceania[4]			
Cattle: Commercialised dairy sector based on grazing. Separate beef cow herd, primarily grazing rangelands[5] and hill country of widely varying forage 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.

TABLE 10.11 (UPDATED) (CONTINUED)
TIER 1 AND TIER 1A ENTERIC FERMENTATION EMISSION FACTORS FOR CATTLE AND BUFFALO[1]

Regional characteristics[8]	Animal category	Tier 1 and Tier 1a Emission Factor[2,3] (kg CH_4 head^{-1} yr^{-1})	Comments[7]
Latin America			
Cattle: 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}
	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	56	Includes mature females, mature males, growing steers/heifers and calves.
	High productivity systems	55	
	Low productivity systems	58	
Buffalo: 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**	68	Includes mature females, mature males, growing animals and calves.
Asia			
Cattle: 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}
	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	54	Includes mature males, mature females, growing and replacement animals, and calves.
	High productivity systems	43	
	Low productivity systems	56	
Buffalo: 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**	68	Includes mature females, mature males, growing animals and calves.

TABLE 10.11 (UPDATED) (CONTINUED)
TIER 1 AND TIER 1A ENTERIC FERMENTATION EMISSION FACTORS FOR CATTLE AND BUFFALO[1]

Regional characteristics[8]	Animal category	Tier 1 and Tier 1a Emission Factor[2,3] (kg CH_4 head^{-1} yr^{-1})	Comments[7]
Africa[6]			
Cattle: 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**	76	Average milk production of 1,300 kg head^{-1} yr^{-1}
	High productivity systems	86	Average milk production of 2,200 kg head^{-1} yr^{-1}
	Low productivity systems	66	Average milk production of 500 kg head^{-1} yr^{-1}
	Other cattle	52	Includes mature males, multi-purpose mature females, growing and replacement animals, and calves.
	High productivity systems	60	
	Low productivity systems	48	
Buffalo: 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**	81	Includes breeding and working males and females, growing animals and calves
Middle East			
Cattle: 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**	76	Average milk production of 2,500 kg head^{-1} yr^{-1}
	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	60	Includes mature males, multi-purpose mature females, growing and replacement animals, and calves.
	High productivity systems	61	
	Low productivity systems	55	
Buffalo: 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**	67	Includes breeding and working males and females, growing animals and calves

TABLE 10.11 (UPDATED) (CONTINUED)
TIER 1 AND TIER 1A ENTERIC FERMENTATION EMISSION FACTORS FOR CATTLE AND BUFFALO[1]

Regional characteristics[8]	**Animal category**	**Tier 1 and Tier 1a Emission Factor[2,3] (kg CH_4 head^{-1} yr^{-1})**	**Comments[7]**
Indian Subcontinent			
Cattle: 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**	73	Average milk production of 1,900 kg head^{-1} yr^{-1}
	High productivity systems	70	Average milk production of 2,600 kg head^{-1} yr^{-1}
	Low productivity systems	74	Average milk production of 1,700 kg head^{-1} yr^{-1}
	Other Cattle	46	Includes mature males, multi-purpose mature females, growing and replacement animals, and calves.
	High productivity systems	41	
	Low productivity systems	47	
Buffalo: 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 males and females, 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 regional characteristics.

[2] The values represent averages within region. Existing values were derived using Tier 2 method and the data in Tables 10A.1–10A.4. Data on a livestock population mix corresponding to low- and high-productivity systems were used.

[3] Uncertainty values from the *2006 IPCC Guidelines* were validated during the development of the emission factors using a Monte Carlo analysis in the *2019 Refinement*, 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 *2006 IPCC Guidelines*.

[4] All data are weighted values, representative of Australia and New Zealand. For Pacific Island nations, GHG inventory compilers may refer to Asian values. GHG inventory compilers from the Island nations of Oceania who wish to use a Tier 1a method could use values from Asia for low productivity systems and the high productivity Tier 1a emission factor from Oceania, whichever is more representative of their production systems.

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

[7] Buffalo mature females livestock sub-category includes lactating dairy mature females.

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

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 (Y_m), defined as the percentage of gross energy intake converted to methane.

There are a wide variety of factors that influence methane conversion rates and due to national circumstances related to breeds, genetic pools as well as particularities of feed and herd interactions, the Y_m factors may vary from region to region. Considering interactions between feed (type and quality) and animals (breed and genetics), it is *good practice* for countries to derive their own Y_m values considering their herds and their typical feed characteristics.

Nonetheless, numerous empirical studies demonstrate the statistical significance of improved feed quality on methane emission rates and biochemical modelling exhibits the biochemical processes that impact methane production with the introduction of improved feeds and 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). When country specific Y_m factors for cattle and buffalo are unavailable, the values provided in Table 10.12 can be used. These estimates are a guide based on the general feed characteristics and production practices found in many countries. It is *good practice* for compilers to justify their choice of Y_m factors based on detailed feed data and research.

In Table 10.12, the Y_m of dairy cows is linked to annual milk production levels and to feed quantity and quality. The lowest Y_m value is associated with highest producing dairy cattle that are fed diets of greater than 70 percent digestibility, and that have percentage of NDF in DMI of less than 35 percent. These diets may be further supplemented with additives or supplements that impact feed efficiency. In cases where countries are achieving high production on high quality silage diets that have digestibility greater than 70 percent but also NDF greater than 35 percent of DMI, compilers should use Y_m values that are midway between the high production and the mid-range productivity Y_m values (6.0 percent GEI).

Diets with digestible fractions that range from 63 to 70 percent and NDF greater than 37 percent DMI, consisting of good quality forages, silages and some grains and have associated milk production between 5000 to 8500 kg year^{-1}, are advised to use Y_m values of 6.3 percent GEI. For low production dairy systems with feed digestibility less than 62 percent and NDF fractions greater than 38 percent, the Y_m factor from the *2006 IPCC Guidelines* (6.5) has been maintained as there is a paucity of reliable globally representative data that could be used to revise that value. In cases where dairy cattle are strictly grazed on low quality forage diets, compilers should use the non-dairy low quality forage value of 7.0 percent GEI.

It is important for inventory compilers to base their decision to select the Y_m on a thorough understanding of national feeding systems. In the case of dairy cows, milk production is presented as a proxy for feed quality and Y_m values in Table 10.12 represent the relationship between feed quality and methane yield. It is possible for a country's national herd, or for parts of the national herd, to have production levels that are inconsistent with the feed quality bounds that are defined by the categories in Table 10.12. In these cases, it is *good practice* to develop their own country-specific Y_m factors, and they should also use their information on animal diets to validate their choice of Y_m against methane yield equations recommended in Niu *et al.* (2018).

With the non-dairy animal category, the non-feedlot diets can be differentiated between forage based diets for which the Y_m value of 7.0 should be used, and mixed concentrate diets or high quality forage diets for which compilers should use the value of 6.3. Reliable estimates for grazing cattle on very poor quality diets are not available, and due to the lack of data, the value of 7.0 is recommended. Countries that have large cattle herds consuming these types of diets are encouraged to develop country-specific values and research efforts should focus on providing more data on these cattle herds.

Emissions from feedlot animals are influenced by the type of grain fed to the animals during the finishing stage, the lowest value of 3.0 can be used when steam-flaked corn is fed at rates greater than 90 percent of the diet in combination with ionophores. Low forage diets of less than 15 percent that incorporate other grains are recommended to use the value of 4.0.

A methane conversion rate of zero is assumed for all juveniles consuming only milk (i.e., milk-fed lambs and calves). While some studies have demonstrated low level emissions from calves during the activation of their rumens (Gerrits *et al*. 2014), the Y_m for the addition of small quantities of emission from unweaned calves does not significantly influence emission factors. For weaned animals the Y_m values indicated for the non-dairy animal category are recommended.

Due to the importance of Y_m in driving emissions, ongoing research is aimed at improving estimates for different livestock and feed combinations. It is important to better understand the 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.

Significant improvements are needed for grazing animals in general, but in particular for low producing dairy cattle on diverse diets and grazing animals on low quality forages particularly in tropical regions as the available data are currently very sparse.

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 10.12 (UPDATED)[6]
CATTLE/BUFFALO METHANE CONVERSION FACTORS (Y_M)

Livestock category	Description	Feed Digestibility (DE %) and Neutral Detergent Fibre (NDF, % DMI)	MY, g CH_4 kg DMI^{-1}	Y_m[3] (%)
[1,4]Dairy cows and Buffalo	High-producing cows[5] (>8500 kg/head/yr^{-1})	DE ≥ 70 NDF ≤ 35	19.0	5.7
	High-producing cows[5] (>8500 kg/head/yr^{-1})	DE ≥ 70 NDF ≥ 35	20.0	6.0
	Medium producing cows (5000 – 8500 kg yr^{-1})	DE 63-70 NDF > 37	21.0	6.3
	Low producing cows (<5000 kg yr^{-1})	DE ≤ 62 NDF >38	21.4	6.5
[2]Non dairy and multi-purpose Cattle and Buffalo	> 75 % forage	DE ≤ 62	23.3	7.0
	Rations of >75% high quality forage and/or mixed rations, forage of between 15 and 75% the total ration mixed with grain, and/or silage.	DE 62–71	21.0	6.3
	Feedlot (all other grains, 0-15% forage)	DE ≥ 72	13.6	4.0
	Feedlot (steam-flaked corn - 0-10% forage)	DE ≥ 75	10.0	3.0

[1] Expert judgement of IPCC authors in consideration of Appuhamy *et al.* (2016); Jayasundara *et al.* (2016) Hellwing *et al.* (2017) 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 non dairy cattle as described in Annex 10B.2.

[4] Y_m cited for dairy cattle are for lactating dairy cows. For dairy 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 with >75% low quality forage the value of (7.0) should be selected.

[5] The lowest Y_m factor for high producing cows refers to feeding situations in which additives or supplements may be used in production that stimulate feed use efficiency and/or milk production. The Y_m values given here do not yet account for any potential reducing effect of additives or supplements on Y_m.

[6] For details on the development of these values, refer to Annex 10B.2.

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 IPCC 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 percent is most appropriate for situations where average dry matter intake per day is between 0.6 and 0.8 kg day^{-1} with a value of 7.0 percent being more appropriate where average intake is <0.6 kg day^{-1}, and a value of 6.5 percent being more appropriate where average intakes are >0.8kg day^{-1}. Table 10.13 also includes a Y_m value for goats (*2006 IPCC Guidelines* did not propose any specific value for goats). This value is based on the analysis of 65 studies that calculated in-vivo enteric CH_4 production from a varied sample of countries and goat breeds (sources and assumptions are explained in Annex 10B.3).

TABLE 10.13 (UPDATED)
SHEEP AND GOATS CH_4 CONVERSION FACTORS (Y_M)

Category	Y_m [1]
Sheep	6.7% $\pm$ 0.9
Goats	5.5% $\pm$ 1.0

Sources and assumptions to calculate the Y_m for goats are detailed in Annex 10B.3.

[1] The ± values are 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 used. For example, 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 10.21:

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

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

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 10.21a:

EQUATION 10.21A (NEW)
METHANE EMISSION FACTORS FOR ENTERIC FERMENTATION FROM A LIVESTOCK CATEGORY

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

Where:

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

DMI = kg DMI day^{-1}

MY = Methane yield, g 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, defined according the the enhanced livestock characterisation that is used in calculation methodology.

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.

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 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 may include:

- variation in feed digestibility (DE);
- breed or genotype variation;
- 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.

The values in Table 10.12 capture some aspects of these factors as they are broadly related to feed quality and animal productivity, however these estimates can be improved for country-specific circumstances using higher tier methods. Accurate estimation of diet DE is singularly important in the estimation of feed intake and enteric methane emission, as previously emphasized. A change of 10 percent in DE will be magnified to a change in CH_4 emissions ranging from 12 to 20 percent depending on the dietary circumstances for which calculations are made. The depression in DE 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. 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). A mechanistic model has been developed in the Netherlands that employs Tier 3 approach (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 Y_m 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 percent 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 dietary starch content is increased 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 DE 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, such as the use of direct methanogen inhibitors, 3-nitrooxypropanol (3-NOP), oxygen-rich anions, fats and oils, ionophores or condensed tannins, and also genetic selection suggests a need to address how they should be reflected in inventory compilation at Tier 2 or Tier 3. First, it is *good practice* that the inventory reflect only those technologies or genotypes developed through selection, 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 validation under field conditions. Second, it is *good practice* that the inventory be accompanied by evidence of the uptake of the technology in agricultural practice, and apply it only to emissions by those livestock where uptake 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, DE and dietary GE content) and Y_m, 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 10.10, 10.11) to estimate enteric emissions, a basic (Tier 1) livestock population characterisation is sufficient. To estimate enteric emissions from livestock using estimation of Gross Energy Intake (Equations 10.21, or 10.21A), 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 refinement.

Activity data

No refinement.

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

No refinement.

10.4 METHANE EMISSIONS FROM MANURE MANAGEMENT

This section describes how to estimate CH_4 produced during the storage and treatment of manure, and from manure deposited on pasture. The Tier 1 approach is based on default emission factors per unit volatile solid (VS) by animal category and manure storage system. The Tier 2 is based on country-specific estimates of volatile solids and the impact of interactions between manure management systems and animal categories on total CH_4 emissions during excretion and storage, including manure treatments such as the production of biogas.

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. When manure is used in the production of biogas, the emissions reported under the manure management category are those occurring on the farm site not resulting from combustion. These include, on-farm storage of the digestion input materials - pre-digestion, leakage during the digestion process and emissions from the storage and application of digestate to agricultural fields (included in Volume 4, Chapter 11, Section 11.2, Nitrous oxide emissions from managed Soils). Emissions from biogas combustion during the production of energy, whether on or off farm should be reported under Volume 2 "Energy".

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 the *2006 IPCC Guidelines*.

To be consistent with consideration of differing productivity classes in section of enteric fermentation, a new Tier 1 was developed. In some 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 were aligned with the updated enteric fermentation section.

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

Tier 1

The Tier 1 method entails multiplying the total amount of VS excreted (from all livestock species/categories) in each type of manure management system by an emission factor for that type of livestock category in the specified climate zone and manure management system (see Equation 10.22). Emissions are summed over all manure management systems and livestock categories. The Tier 1 method is applied using IPCC default VS excretion rates (See Table 10.13a), default typical animal mass (see Table 10A.5), default CH_4 Emission Factors (see Table 10.14), and default animal waste management systems (AWMS). Animal waste management system (manure management systems) data have been collected for regions and countries by the FAO and average manure fractions treated by different management systems are presented in Annex 10A.2, Tables 10A.6 to 10A.9. As 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. Breakdowns of manure management systems by regional climate zone and production system can be found in the supplemental data supplied with this chapter. Please refer to "Raw data for cattle and buffalo spreadsheet". Further finer-scale country-specific data is also available from FAO GLEAM databases (FAO 2017).

An advanced Tier 1a method has been developed as an alternative for countries with differentiated agricultural systems in which there is a coexistence of 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 productivity based emission factors given for an animal category provides an alternative or intermediary option. The advanced Tier 1a approach will provide an 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.

The main differences between the Tier 1 and Tier 2 calculations is whether default information or country-specific information is used in the calculation of emissions from manure management system. The Tier 2 system provides a much wider group of options for estimating emissions from different manure management systems.

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 steps are used to estimate CH_4 emissions from manure management:

Step 1: Collect population data based on the Livestock Population Characterization (see Section 10.2).

Step 2: Identify default (Table 10A.5) or collect country-specific typical animal mass (TAM) values. Calculate volatile solid excretion according to Equation 10.22a or develop country-specific volatile solid excretion rates according to Equation 10.24.

Step 3: Collect country-specific information on manure management system methods and develop country-specific manure management system fractions or use default manure storage fractions presented in Annex Tables 10A.6 to Tables 10A.9.

Step 4: Identify either default emission factors Table 10.14 or build country-specific emission factors for each livestock subcategory based on climate zones and manure management system fractions.

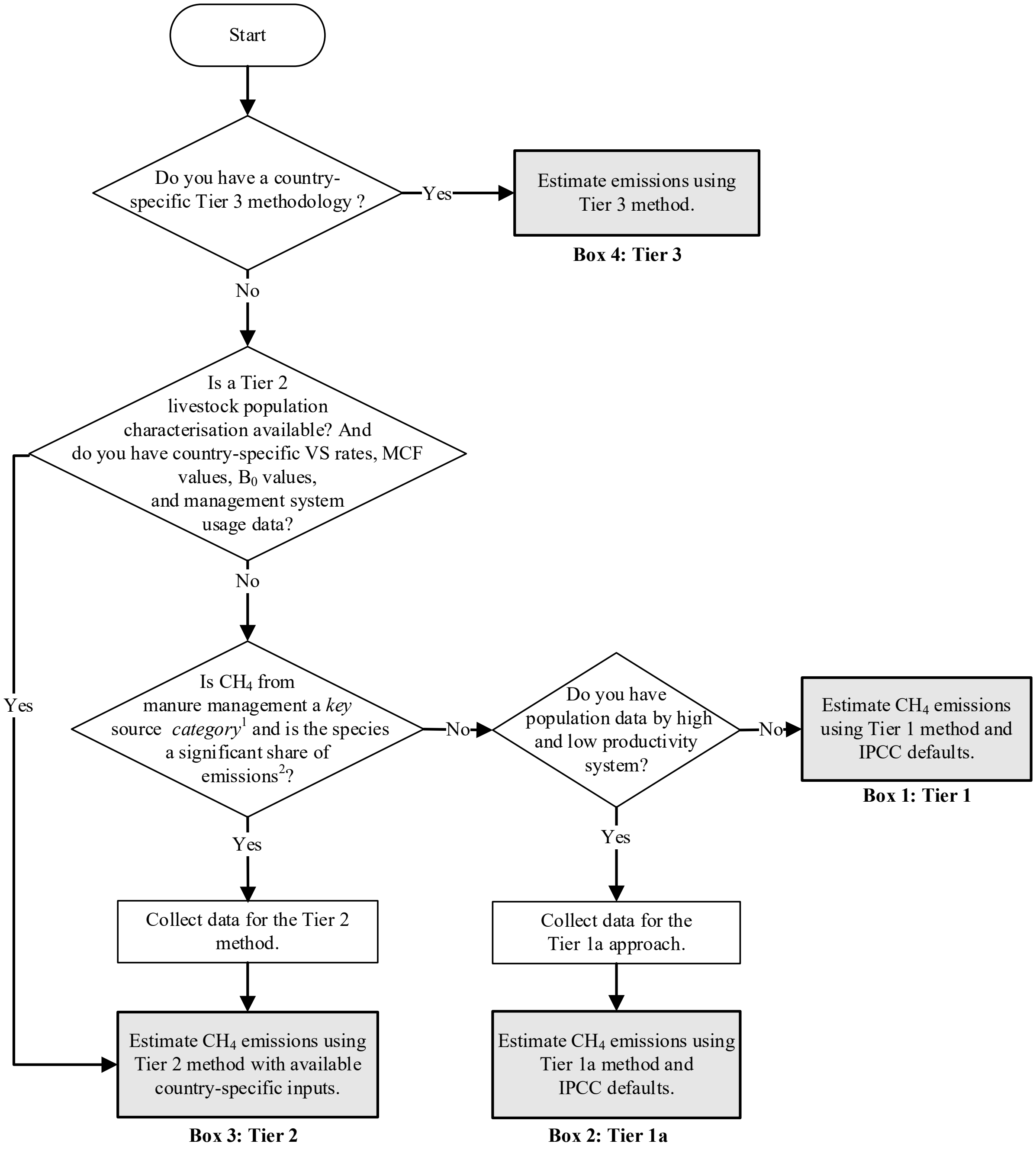
- Tier 1: Identify default values (Table 10.14) for emission factors for each livestock category in terms of grams of methane per kg VS per year for the appropriate climate zone and productivity class if using advanced Tier 1a.
- Tier 2: Select local manure management specific methane conversion factors (MCF's, Table 10.17) for different climate zones and the animal categories specific maximum methane producing capacity (B_0).

Step 5: Calculate methane emission for each livestock subcategory.

- Tier 1: According to Equation 10.22 for each livestock category, climate zone (include production level if using Tier 1a) multiply the livestock category population (**Step 1**) by quantity of volatile solid (**Step 2**) by the manure storage fraction (**Step 3**) and the default emission factor (**Step 4**).
- Tier 2: According to Equation 10.23, for each livestock category and climate zone calculate the country-specific emission factor based on the country-specific or default quantity of volatile solids (**Step 2**), the manure management system fraction (AWMS) and the MCF and B_0 factors (**Step 4**); To estimate total emissions, the country specific emission factor is then multiplied by the population number (**Step 1**).

Step 6: Sum emissions from all defined livestock categories to determine national emissions.

Figure 10.3 (Updated) 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 1 uses Equation 10.22 for both simple Tier 1 or advanced Tier 1a methods.

EQUATION 10.22 (UPDATED)
CH_4 EMISSIONS FROM MANURE MANAGEMENT (TIER 1)

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

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*, when applicable

$VS_{(T,P)}$ = annual average VS excretion per head of species/category *T*, for productivity system *P*, when applicable in kg VS $animal^{-1}$ yr^{-1} (Table 10.13a calculated by Equation 10.22a)

$AWMS_{(T,S,P)}$ = 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*, when applicable; dimensionless, default regionally specific AWMS fractions are found in Tables 10A.6 through 10A.9 in Annex 10A.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*, when applicable (Table 10.14), g CH_4 kg VS^{-1}

S = manure management system

T = species/category of livestock

P = high productivity system or low productivity system for use in advanced Tier 1a – omitted if using a simple Tier 1 approach

10.4.2 Choice of emission factors

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

Tier 1

When using the Tier 1 method, methane emission factors per unit of VS by livestock category or subcategory are used. Default emission factors by animal productivity class, manure management system and climate zone are presented in Table 10.14 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 climate zone.

Tables 10A.5 through 10A.9 located in Annex 10A.2 present the underlying assumptions used for each region. Countries using a Tier 1 method to estimate methane emissions from manure management should review the regional variables in these tables to identify the region that most closely matches their animal operations, and use the default emission factors for that region.

Annual volatile solid 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 calculated based on estimates of dry matter intake (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 10.13a 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 10.22a for a Tier 1 calculation. The TAM should be consistent with median weight of the animal during its production stage. Typically, for animals used in meat production systems, this is the median weight of the animal during its growth period. Animals that are kept for the production of products (milk, eggs), draft or other uses would use the typical live weight of the animal herd.

Volatile solids should be calculated according to Equation 10.22a, either for the simple Tier 1 or the advanced Tier 1a, where parameters are split by their productivity class in the calculaton of volatile solid excretion. Note that if countries are mixing Tier 1 and Tier 2 methods and volatile solids are calculated through Equation 10.22A and are applied in Equation 10.23 (Tier 2), the constant of 365 should be removed from that equation.

EQUATION 10.22A (NEW)
ANNUAL VS EXCRETION RATES (TIER 1)

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

Where:

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

$VS_{rate(T,P)}$ = default VS excretion rate, for productivity system P (when applicable), kg VS (1000 kg animal mass)$^{-1}$ day^{-1} (see Table 10.13a)

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

The calculation is a simple linear adjustment, so in the case of an animal that is 500 kg of weight, the VS emission rate will be half of the rate presented per 1000 kg live weight.

Default TAM values are provided in Table 10A.5 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 and animal size 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 10.14 shows the default emission factors per kg of volatile solid excretion and year for all animal categories for each manure management system and climate zone. Emission factors are listed for the climate zone where the livestock manure is managed. 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 t*ables, 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. Emission factors result from the MCFs in Table 10.17 and the B_0 in Table 10.16 and as a result, vary by animal category and manure management system, with liquid systems demonstrating higher emissions per unit VS. Lower emission factors associated with low productivity systems are representative of the lower B_0 values associated with lower quality feeds and manures with high C to N ratios.

TABLE 10.13A (NEW)
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 subcontinent		
					Mean	High PS[1]	Low PS[1]	Mean	High PS	Low PS	Mean	High PS	Low PS	Mean	High PS	Low PS	Mean	High PS	Low PS
Dairy cattle[4]	9.2	8.4	6.7	6.0	7.9	9.0	7.1	18.2	21.7	15.2	10.7	8.4	11.8	9.0	8.1	9.2	14.1	9.1	16.1
Other cattle[4]	7.6	5.7	7.6	8.7	8.5	8.1	8.6	12.1	10.2	12.7	12.3	9.3	14.5	9.8	6.8	10.8	12.2	13.5	12.0
Buffalo[4]	NA	7.7	6.2	NA	11.2	NE		12.9	NE		9.8	NE		13.5	NE		15.2	NE	
Swine[3]	3.3	4.5	4.0	4.0	5.0	3.3	8.3	7.2	4.3	8.7	4.3	3.9	7.2	5.8	4.3	7.1	7.7	5.5	8.7
Finishing	3.9	5.3	4.9	5.6	6.4	4.3	10.0	8.2	5.3	9.4	4.9	4.4	7.8	6.8	5.1	8.1	8.6	6.5	9.5
Breeding	1.8	2.4	2.0	2.1	2.7	1.7	4.8	4.4	2.4	6.0	2.5	2.3	4.6	3.4	2.3	4.3	4.6	3.0	5.5
Chicken[3]	14.5	12.3	12.6	15.4	13.5	13.3	15.7	12.6	12.3	13.0	14.2	14.1	16.5	11.2	10.6	14.3	14.9	14.3	15.7
Hens ±1 yr	9.4	8.6	9.4	8.6	10.1	9.3	14.7	10.2	8.0	11.6	9.0	8.4	15.8	9.3	8.5	12.8	13.2	11.6	14.6
Pullets	5.9	5.3	5.9	6.2	7.6	5.7	18.5	12.0	5.8	16.5	6.8	5.6	18.5	7.5	5.4	17.7	13.2	6.8	18.9
Broilers	16.8	16.1	16.0	18.3	15.6	15.5	17.8	15.9	16.0	15.4	17.7	17.7	17.9	15.7	15.6	17.1	17.7	17.6	18.2
Turkeys[8]	10.3																		
Ducks[8]	7.4																		
Sheep[3]	8.2				8.3														
Goats[5]	9				10.4														
Horses[8]	5.65				7.2														
Mules/ Asses[8]	7.2																		
Camels[8]	11.5																		

TABLE 10.13A (NEW) (CONTINUED)
DEFAULT VALUES FOR VOLATILE SOLID EXCRETION RATE (KG VS (1000 KG ANIMAL MASS)-1 DAY^{-1})

[1] High PS and Low PS refer to high and low productivity systems required for Tier 1a 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 NA refers to situations in which these animal categories do not occur in these regions.

[3] Values are taken from FAO GLEAM databases (FAO 2017).

[4] Values are derived from diets used in the calculation of enteric fermentation Tier 1 emission factors.

[5] Calculations are detailed in Annex 10B.3.

[6] North African countries may wish to use values from the Middle East if their production systems are more similar.

[7] All data are weighted values, representative of Australia and New Zealand. For Pacific Island nations, GHG inventory compilers may refer to Asian values. GHG inventory compilers from the Island nations from Oceania may wish to use a Tier 1a approach. In this case, they could used values from Asia, or low productivity systems and high Tier 1a emission factor from Oceania, whichever is more representative to their production systems.

[8] Values are derived directly from the parameters reported in Table 10A-9 of the *2006 IPCC Guidelines*.

TABLE 10.14 (UPDATED)
METHANE EMISSION FACTORS BY ANIMAL CATEGORY, MANURE MANAGEMENT SYSTEM AND CLIMATE ZONE (G CH_4 KG VS^{-1}) [7]

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
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, Pit storage > 1 month [5]	33.8	41.8	22.5	22.5	59.5	65.9	94.9	122.2	117.4	119.0
		Solid storage	3.2				6.4		8.0			
		Dry lot	1.6				2.4		3.2			
		Daily spread	0.2				0.8		1.6			
		Anaerobic Digestion -Biogas[8]	3.2				3.7		3.7			
		Burned for fuel	16.1									
	Low Productivity[1]	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, Pit storage > 1 month [5]	18.3	22.6	12.2	12.2	32.2	35.7	51.4	66.2	63.6	64.5
		Solid storage	1.7				3.5		4.4			
		Dry lot	0.9				1.3		1.7			
		Daily spread	0.1				0.4		0.9			
		Anaerobic Digestion -Biogas[8]	9.2				9.5		9.5			
		Burned for fuel	8.7									

TABLE 10.14 (UPDATED) (CONTINUED)
METHANE EMISSION FACTORS BY ANIMAL CATEGORY, MANURE MANAGEMENT SYSTEM AND CLIMATE ZONE (G CH_4 KG VS^{-1}) [7]

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
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, Pit storage > 1 month[5]	25.3	31.4	16.9	16.9	44.6	49.4	71.2	91.7	88.0	89.2
		Solid storage	2.4				4.8		6.0			
		Dry lot	1.2				1.8		2.4			
		Daily spread	0.1				0.6		1.2			
		Anaerobic Digestion -Biogas[8]	2.4				2.7		2.8			
		Burned for fuel	12.1									
	Low Productivity[1,6]	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, Pit storage > 1 month[5]	18.3	22.6	12.2	12.2	32.2	35.7	51.4	66.2	63.6	64.5
		Solid storage	1.7				3.5		4.4			
		Dry lot	0.9				1.3		1.7			
		Daily spread	0.1				0.4		0.9			
		Anaerobic Digestion -Biogas[8]	9.2				9.5		9.5			
		Burned for fuel	8.7									

TABLE 10.14 (UPDATED) (CONTINUED)
METHANE EMISSION FACTORS BY ANIMAL CATEGORY, MANURE MANAGEMENT SYSTEM AND CLIMATE ZONE (G CH_4 KG VS^{-1}) [7]

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
		Liquid/Slurry, and Pit storage below animal confinements > 1 month[5]	63.3	78.4	42.2	42.2	111.6	123.6	177.9	229.1	220.1	223.1
		Liquid/Slurry, and Pit storage below animal confinements < 1 month[5]	18.1	24.1	12.1	12.1	39.2	45.2	75.4	114.6	108.5	126.6
		Solid storage	6.0				12.1		15.1			
		Dry lot	3.0				4.5		6.0			
		Daily spread	0.3				1.5		3.0			
		Anaerobic Digestion - Biogas[8]	6.0				6.8		7.0			
		Burned for fuel	30.2									
	Low Productivity[1]	Uncovered anaerobic lagoon	116.6	130.2	97.2	95.2	141.8	147.7	147.7	155.4	155.4	155.4
		Liquid/Slurry, and Pit storage below animal confinements > 1 month[5]	40.8	50.5	27.2	27.2	71.9	79.7	114.6	147.7	141.8	143.8
		Liquid/Slurry, and Pit storage below animal confinements < 1 month[5]	11.7	15.5	7.8	7.8	25.3	29.1	48.6	73.8	69.9	81.6
		Solid storage	3.9				7.8		9.7			
		Dry lot	1.9				2.9		3.9			
		Daily spread	0.2				1.0		1.9			
		Anaerobic Digestion - Biogas[8]	20.6				21.1		21.2			
		Burned for fuel	19.4									

TABLE 10.14 (UPDATED) (CONTINUED)
METHANE EMISSION FACTORS BY ANIMAL CATEGORY, MANURE MANAGEMENT SYSTEM AND CLIMATE ZONE (G CH_4 KG VS^{-1}) [7]

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
Poultry	High productivity	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	154.2	198.6	190.7	193.4
		Solid storage	5.2				10.5		13.1			
		Dry lot	2.6				3.9		5.2			
		Anaerobic Digestion - Biogas[8]	5.2				10.5		13.1			
		Burned for fuel	2.6									
	Low productivity[1]	All Systems	2.4									
Sheep	High productivity	Solid storage	2.5				5.1		6.4			
		Dry lot	1.3				1.9		2.5			
	Low productivity[1]	Solid storage	1.7				3.5		4.4			
		Dry lot	0.9				1.3		1.7			
Goats	High productivity	Solid storage	2.4				4.8		6.0			
		Dry lot	1.2				1.8		2.4			
	Low productivity[1]	Solid storage	1.7				3.5		4.4			
		Dry lot	0.9				1.3		1.7			

TABLE 10.14 (UPDATED) (CONTINUED)
METHANE EMISSION FACTORS BY ANIMAL CATEGORY, MANURE MANAGEMENT SYSTEM AND CLIMATE ZONE (G CH_4 KG VS^{-1}) [7]

Livestock species	Productivity Class	Manure Storage System[4]	Cool	Temperate	Warm
Camels	High productivity	Solid storage	3.5	7.0	8.7
		Dry lot	1.7	2.6	0.0
	Low productivity[1]	Solid storage	2.8	5.6	7.0
		Dry lot	1.4	2.1	2.8
Horses	High productivity	Solid storage	4.0	8.0	10.1
		Dry lot	2.0	3.0	4.0
	Low productivity[1]	Solid storage	3.5	7.0	8.7
		Dry lot	1.7	2.6	3.5
Mules/ Asses	High productivity	Solid storage	4.4	8.8	11.1
		Dry lot	2.2	3.3	4.4
	Low productivity[1]	Solid storage	3.5	7.0	8.7
		Dry lot	1.7	2.6	3.5
All Animals	High and Low Productivity	Pasture Range and Paddock	0.6		

All values are calculated based on MCFs and B_0s reported in Tables 10.17 and 10.16, respectively, using the equation MCF*B_0*0.67.

[1] For the application of Tier 1, for all regions other than North America, Europe and Oceania the Tier 1 default values are the low productivity EFs. Pasture range and paddock emission factor is based on observation in the updated version of Cai *et al*. (2017) database (see Annex 10B.6). No differences were observed 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 temperate.

[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.

[6] Buffalo emission factors are equivalent to low productivity non dairy animals.

[7] Uncertainty is ±30% consisten with the *2006 IPCC Guidelines*.

[8] Anaerobic digestion biogas values: for high productivity are based on emission estimates from high quality gas-tight digesters and average MCFs for storage whereas, for low productivity are based on emission estimates from high digester leakage rates and average MCFs for storage leakage rates. Countries should consider the type and quality of digesters used in their individual countries in evaluating what emission factors they choose to employ as opposed to the level of productivity for anaerobic digesters only.

TABLE 10.15 (UPDATED)
MANURE MANAGEMENT METHANE EMISSION FACTORS FOR DEER, REINDEER, RABBITS, OSTRICH AND FUR-BEARING ANIMALS AND DERIVATION PARAMETERS APPLIED

Livestock	CH_4 emission factor (kg CH_4 head^{-1} yr^{-1})	VS (kg VS day^{-1})[4]	B_0 (m^3 kg VS)[4]
Deer[1]	0.22	NR	NR
Reindeer[2]	0.36	0.39	0.19
Rabbits[3]	0.08	0.10	0.32
Fur-bearing animals (e.g., fox, mink)[2]	0.68	0.14	0.25
Ostrich	5.67	1.16	0.25

The uncertainty in these emission factors is ±30 %.

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

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

[3] Judgement of the IPCC Expert Group.

[4] Table 10A-9 of the *2006 IPCC Guidelines*.

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_0). 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_0 varies by animal species and feed regime 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. CH_4 emissions from co-digestion of on-farm organic resources (crop residues, energy crops) need to be reported under the source category '3.A2(k) – Co-digestates'.

Animal waste management system characteristics (AWMS)*:* 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. Theoretically the value can range from 0 to 100 percent. 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 76 to 80 percent. Manure managed as dry material in cold climates does not readily produce methane, and consequently has an MCF of about 1 percent.

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[5]

$$EF_{(T)} = \left(VS_T \bullet 365\right)\left[B_{0(T)} \bullet 0.67 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet AWMS_{(T,S,k)}\right]$$

Where:

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

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

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

$B_{0(T)}$ = maximum methane producing capacity for manure produced by livestock category *T*, m^3 CH_4 kg^{-1} of VS excreted

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

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

$AWMS_{(T,S,k)}$ = 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 available in Annex 10A.1 and 10A.2 to fill gaps.There is no defined threshold to indicate how much country-specific information is required for a Tier 2 method, but it is understood that increased use of country-specific information improves emission estimates, by better representing local production characteristics.

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_0 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

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[5] When biogas is produced in on-farm plants, emissions from on-farm co-digestates can be calculated separately using a similar equation: $CH_{4(cdg)}$=C_{cdg} *B0*0.67*(MCF/100) and added to methane totals, where C_{cdg} is the total kg dry matter of the co-digested material and other parameters are as defined in Equation 10.23

energy (GE) intake (Section 10.2, Equation 10.16) and its fractional digestibility, DE, in the process of estimating enteric methane emissions.

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

EQUATION 10.24 (UPDATED)
VOLATILE SOLID EXCRETION RATES

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

Where:

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

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

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

$(UE \bullet GE)$ = 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 percent or more grain in the diet or for swine). Use country-specific values where available.

ASH = the ash content of feed calculated as a fraction of the dry matter feed intake (e.g., 0.06 for sows: Dämmgen *et al*. 2011). Use country-specific values where available.

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

Representative DE percent 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_0 values

The maximum methane-producing capacity of the manure (B_0) varies by species and diet. The preferred method to obtain B_0 measurement values is to use data from country-specific published sources, measured with a standardised method. It is important to standardise the B_0 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_0 measurement values are not available, default values are provided in Table 10.16 where data is summarized from Table 10A-4 through 10A-9 of *2006 IPCC Guidelines*.

MCFs

MCFs are determined for a specific manure management system and represent the degree to which B_0 is achieved. Default methane conversion factors (MCFs) are provided in Table 10.17 for different manure management systems. The amount of methane generated by a specific manure management system is affected by the amount of volatile solids, 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 10.17 include the effect of longer retention times.

Liquid-based systems are sensitive to temperature effects. 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 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 10A.2, Figure 10A.1. Inventory compilers should consult long-term averages from national meteorological statistics and evaluate the climate zones for each region of their country based on the criteria outlined in Annex 10A.2. It is *good practice* to assure consistency of the definition of climate zones for all sectors of the inventory that may be influenced by climate.

Manure removal statistics should be taken from farm practice surveys or from expert consultation. Compilers should develop an estimate of the average number of manure removals per year and the months of the highest frequency of removals. If regional practices vary, compilers should develop MCFs that are representative of regional practice by entering consistent manure removal statistics with regional temperature profiles. If regional MCFs are calculated, the national MCF should be weighted based on the number of animals feeding into the regional manure management systems represented by the manure removal profile and the regional temperature profile.

In cases in which countries lie in multiple climate zones, it is *good practice* for compilers, if possible, to disaggregate 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.2. If regional MCFs are calculated, the national MCF should be weighted based on the number of animals feeding into the regional manure management systems represented by the manure removal profile and the regional temperature profile. Global temperature data can be downloaded from a number of sites such as the National Oceanic and Atmospheric Administration (NOAA) website, long-term monthly averages should be used for the development of MCFs.

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.3 and a simple spreadsheet model is available in the supplemental data supplied with this chapter. Please refer to "Raw data for cattle and buffalo spreadsheet".

For manure deposited by grazing animals onto pastures, ranges and paddocks, it is recommended to use a value that is consistent with the emission factor provided in Table 10.14. In this table, a single emission factor per unit of volatile solid excretion is provided, as an analysis of 45 data points showed that there was no significant difference between climatic zones nor were there differences per animal category (Annex 10B.6). Therefore, the MCF reported in Table 10.17 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 single emission factor was judged by the expert panel to be more accurate than emission factors estimated from regionally based MCFs and animal category based B_0, considering the differences in processes that would result in methane production between excretion of VS on pasture, range and paddock relative to typical manure storage systems.

Anaerobic digestion is an important manure management technology that provides renewable energy through biogas production. There is a wide variety of digesters available of varyinig quality and use including industrial centralised biogas digester plants, and animal farm based biogas digesters. Some biogas digesters may co-digest energy crops and different types of organic waste in varying combinations. The quality of the digester and the pre- and post-storage of digester input and output (digestate) are the main factors in determining the methane that is lost to the atmosphere before, during and after digestion.

Default methane conversion factors (MCFs) of anaerobic digesters are provided in Table 10.17. Default values for biogas digesters presented include the estimated MCF from combinations of either high and low quality anaerobic digetsers with different types and qualities of storage systems. The approach to calculate these MCFs, based on Haenel *et al*. (2018) is outlined in Annex 10A.4. The main factors considered in differentiating between digester systems are the degree of leakage from the digester itself (varying between 1 and 10 percent of the methane production potential B_0) and the loss of CH_4 from the digeste storage system.

All manure management methane emission factors are based on experimental measurements that typically combine the VS and bedding. Based on current scientific literature, these two sources cannot be separated. More refined measurements of methane from manure storage and stages of storage are for further scientific development. 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 (including bedding) 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.

CH_4 emissions from multiple Manure Management systems

If manure is managed in multiple systems, by default, manure emission factors should be allocated to the dominant storage systems; but a country specific emission factor could be developed considering the emissions originating from all systems used in storage prior to field applicaton.

A number of combinations are possible and it is beyond the scope of these guidelines to provide guidance for all possibilities but common examples include: i.) manure flushed from a dairy freestall barn to an anaerobic lagoon that first pass through a solids separation unit where some of the manure nitrogen is removed and managed as a solid. In this case, the methodology must integrate an additional fraction to the AWMS system that tranfers those solids to a solid storage systems; ii.) pit storage that is flushed to a larger holding tank. In this case, the methodology must consider modifications to the B_0 that result from the initial storage period based on the length of the storage and the temperature dependant MCF. iii.) solid manure pack that is allowed to accumulate, and periodically transferred to heaps. Likewise in this case, the impact of the prestorage period to the B_0 of the manure in the secondary storage should be adjusted to consider the emissions that occurred during the initial storage.

In cases in which country-specific methodologies are used to estimate emissions from multiple systems rely on B_0s and MCFs as defined in Tables 10.16 and 10.17, these methodologies should assure that the total annual B_0 of the stored manure is not reduced or increased during the application of the methodology. Further, methodologies that require additional fractionation of manure must assure that calculated VS input is not reduced or increased.

TABLE 10.16A (UPDATED)
DEFAULT VALUES FOR MAXIMUM METHANE PRODUCING CAPACITY (B_0) (M^3 CH_4 KG^{-1} VS)

Category of animal [2]	Region					
					Other Regions[1]	
	North America	Western Europe	Eastern Europe	Oceania	High productivity systems	Low productivity systems
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
All other poultry	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					

Sources: All values are consistent with *2006 IPCC Guidelines* values from Annex 10A.2 with the exception of PRP, taken from the analysis described in Annex 10B.6.

[1] For other regions, low productivity is considered the default value for Tier 1 if not using the Tier 1a.

[2] Only presenting values for manure, compilers are recommended to consult scientific literature or develop country-specific B_0 values for the different codigestates that may be used in anaerobic digesters.

Uncertainty values are ±15 percent.

Table 10.17 (Updated)
Methane Conversion Factors for manure management systems

System[4]		MCFs by climate zone									
		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
Uncovered anaerobic lagoon[7]		60%	67%	50%	49%	73%	76%	76%	80%	80%	80%
Liquid/Slurry, and Pit storage below animal confinements[1]	1 Month	6%	8%	4%	4%	13%	15%	25%	38%	36%	42%
	3 Month[8]	12%	16%	8%	8%	24%	28%	43%	61%	57%	62%
	4 Month[9]	15%	19%	9%	9%	29%	32%	50%	67%	64%	68%
	6 Month[9]	21%	26%	14%	14%	37%	41%	59%	76%	73%	74%
	12 Month[9]	31%	42%	21%	20%	55%	64%	73%	80%	80%	80%
Cattle and Swine deep bedding[5]	> 1 month[10]	21%	26%	14%	14%	37%	41%	59%	76%	73%	74%
	< 1 month[11]	2.75%				6.50%		18%			
Solid storage[6,12]		2.00%				4.00%		5.00%			
Solid storage – Covered/compacted[6,13]		2.00%				4.00%		5.00%			
Solid storage – Bulking agent addition[6,14]		0.50%				1.00%		1.50%			
Solid storage – Additives[6,15]		1.00%				2.00%		2.50%			
Dry lot[16]		1.00%				1.50%		2.00%			
Daily spread[17]		0.10%				0.50%		1.00%			
Composting - In-vessel[4,18]		0.50%									
Composting - Static pile (Forced aeration)[4,6,19]		1.00%				2.00%		2.50%			
Composting - Intensive windrow[4,20]		0.50%				1.00%		1.5%			
Composting – Passive windrow (Unfrequent turning)[3,4,6,21]		1.00%				2.00%		2.50%			

Table 10.17 (Updated) (Continued)
Methane Conversion Factors for manure management systems

System[4]	MCFs by climate zone									
	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
Pasture/Range/Paddock[2]	0.47%									
Poultry manure with and without litter[22]	1.50%									
Aerobic treatment[23]	0.00%									
Burned for fuel[24]	10.00%									
Anaerobic Digester[25], Low leakage, High quality gastight storage, best complete industrial technology	1.00%									
Anaerobic Digester[25], Low leakage, High quality industrial technology, low quality gastight storage technology	1.41%									
Anaerobic Digester[25], Low leakage, High quality industrial technology, open storage	3.55%				4.38%		4.59%			
Anaerobic Digester[25], High leakage, low quality technology, high quality gastight storage technology	9.59%									
Anaerobic Digester[25], High leakage, low quality technology, low quality gastight storage technology	10.00%									
Anaerobic Digester[25], High leakage, low quality technology, open storage	12.14%				12.97%		13.17%			

TABLE 10.17 (UPDATED) (CONTINUED)
METHANE CONVERSION FACTORS FOR MANURE MANAGEMENT SYSTEMS

[1] The initial judgement of IPCC Expert Group supported by additional new research. See Annex 10B.7 for additional details. Suggested default values are equivalent to liquid systems with 6 month retention time if retention times are unknown. A reduction of 40% due to crust cover may be applied only when a thick, dry, crust is present. Thick dry crusts occur in systems in which organic bedding is used in the barn and is allowed to be flushed into the liquid storage tank and solids are not separated from the manure stream and further the surface is not exposed to regular heavy precipitation that may disrupt the surface. Sources: 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%). Sources: 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 B_0 value of 0.19 m^3 CH_4 kg^{-1} of VS excreted to maintain consistency with the data in the 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 due to microbial heat production.

[5] Articles from which these values were derived were for cattle and swine, but for other animal production systems that use deep bedding these values are proposed to be used as surrogates. Suggested default values are equivalent to liquid systems with 6 month retention time.

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

[7] 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.

[8] The avg °C for Cool Temperate Moist, Cool Temperate Dry, Warm Temperate Moist, Warm Temperate Dry, Tropical Montane, Tropical Wet, Tropical Moist, Tropical Dry were 4.6, 5.8, 13.9, 14.0, 21.5, 25.9, 25.2, 25.6 respectively.

[9] 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.

[10] 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 retention time when possible.

[11] 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.

[12] Expert judgement based on IPCC (2006) and update supported by Pardo *et al*. (2015). Emissions in temperate climate can be double relative to a cool climate.

[13] Expert judgement based on Pardo *et al*., (2015). Emissions in the same range than solid storage.

[14] Expert judgement based on Pardo *et al*. (2015). Estimated reduction of 75% due to bulking agent addition.

[15] Expert judgement based on Pardo *et al*. (2015). Estimated reduction of 50% due to additives addition.

[16] Judgement of IPCC 2006 Expert Group in combination with Hashimoto & Steed (1993).

[17] Hashimoto & Steed (1993).

[18] Judgement of IPCC 2006 Expert Group and Amon *et al*. (1998a). MCFs are less than half of solid storage. Not temperature dependant.

[19] Expert judgement updated 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.

[20] Judgement of IPCC Expert Group and Amon *et al*. (1998a). MCFs are slightly less than solid storage. Less temperature dependant.

[21] 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 CH_4 emissions.

[22] Judgement of 2006 IPCC Expert Group. MCFs are similar to solid storage or to dry lot but with generally constant warm temperatures.

[23] 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.

[24] Judgement of IPCC 2006 Expert Group in combination with Safley *et al*. (1992).

[25] Calculations based on Haenel *et al*. (2018), outlined in Annex 10A.4.

10.4.3 Choice of activity data

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

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

Inventory agencies in countries with varied climatic conditions are encouraged to obtain population data for each major climatic zone as defined in Volume 4, Chapter 3, Annex 3A.5, Figure 3A.5.1 or the 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 10.18 summarizes the main types of manure management systems. Quantitative data should be used to distinguish whether the system is judged to be a solid storage or liquid/slurry. The borderline between dry and liquid can be drawn at 15 percent 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 from each system (see N_2O emissions from multiple Manure Management systems). Manure removal statistics should also be monitored where possible. It is recommended that agencies develop an estimate of the average number of manure removals per year and the months of the highest frequency of removals. If regional practices vary and also represent significant differences in temperature profiles, statistics that are representative of regional practice should be tracked combining the appropriate manure removal statistics together with regional temperature profiles.

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 (UPDATED)
DEFINITIONS OF MANURE MANAGEMENT SYSTEMS[3]

System		Definition
Pasture/Range/Paddock (PRP)		The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread		Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Solid storage		The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation. Solid stores can be covered or compacted. In some cases, bulking agent or additives are added.
Solid storage-Covered/compacted		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		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		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 reduces CH_4 emissions.
Dry lot		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 [1]		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		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		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	Digesters of high quality and low leakage	Animal manure with and without straw is collected and anaerobically digested in a containment vessel. Co-digestion with other waste or energy crops may occur. Digesters are designed, constructed and operated according to industrial technology standard for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4. Biogas is captured and used as a fuel. Digestate is stored either in open storage, in covered storage with no leakage control, or in gas tight storage with gas recovery or flaring.
	Digesters with high leakage	Animal manure with and without straw is collected and anaerobically digested in covered lagoon. Digesters are used for waste stabilization by the microbial reduction of complex organic compounds to CO_2 and CH_4. Biogas is captured and flared or used as a fuel. After anaerobic digestion, digestate is stored either openly, covered, or gas tightly.
Burned for fuel		The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel.

Table 10.18 (Updated) (Continued)
Definitions of manure management systems

System		Definition
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. 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[2]	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[2]	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[2]	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		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		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.

[1] Covers on manure management systems can impact emissions of direct N_2O, CH_4 and NH_3. With N_2O and CH_4 emission, the effect of the cover depends upon character of the cover material.

[2] 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.

[3] Comparative definitions with the EMEP/EEA Air Pollutant Emission Inventory 2016 Guidebook can be found in Annex 10A.2, Table 10A.10.

10.4.4 Uncertainty assessment

No refinement.

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

No refinement.

10.5 N_2O EMISSIONS FROM MANURE MANAGEMENT

This section describes how to estimate the N_2O produced, directly and indirectly, during the storage and treatment of manure before it is applied to land or otherwise used for feed, fuel, or construction purposes. The approach is based on N excretion, emission factors for N_2O emissions, as well as 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 NO_x 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".

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 calculating N_2O emissions from managed soils (see Chapter 11, Section 11.2). The methodology to estimate manure nitrogen that is directly applied to soils, or available for use in feed, fuel, or construction purposes is described in this chapter under Section 10.5.4 "Coordination with reporting for N_2O emissions from managed soils".

10.5.1 Choice of method

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

Direct N_2O emissions from Manure Management

Tier 1

The Tier 1 method entails multiplying the total amount of N excretion (from all livestock species/categories) in each type of manure management system by an emission factor for that type of manure management system (see Equation 10.25). Emissions are then summed over all manure management systems. The Tier 1 method is applied using IPCC default N_2O emission factors, default nitrogen excretion data, and default manure management system data (see Annex 10A.2, Tables 10A.5 to 10A.9 for default animal weights and manure management system allocations). It is recommended to consult the methane and enteric fermentation sections to clarify how to implement the Tier 1a 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 same as that used to characterize methane emissions from manure management (see Section 10.4). For example, if Tier 1 default emission factors are used for calculating CH_4 emissions, then the manure management systems usage data from Tables 10A.5 to 10A.9 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 ($Nex_{(T,P)}$) for each defined livestock species/category T, and productivity system P, when applicable;

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 ($AWMS_{(T,S,P)}$);

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. If manure is managed in multiple systems, 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 10.25 (UPDATED)
DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

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

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, for productivity system *P*, when applicable

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

$N_{cdg(s)}$ = annual nitrogen input via co-digestate in the country, kg N yr^{-1}, where the system (s) refers exclusively to anaerobic digestion

$AWMS_{(T,S,P)}$ = 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 1a 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 1a approach

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

As is the case in the calculation of methane emission, countries may choose to consider if they have significantly different production systems in their country and apply a Tier 1a approach. In this case, compilers should consider the productivity class of their animal system as included in the calculation of CH_4 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 10.5.6 in the subsection 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 10.26). N losses are then summed over all manure management systems. The Tier 1 method is applied using default nitrogen excretion data, default manure management system data, animal weights (see Annex 10A.2, Tables 10A.5 to 10A.9) and default fractions of N loss from manure management systems (see Table 10.22):

EQUATION 10.26 (UPDATED)
N LOSSES DUE TO VOLATILISATION FROM MANURE MANAGEMENT

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

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, for productivity system *P*, when applicable

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

$N_{cdg(s)}$ = amount of nitrogen from co-digestates added to biogas plants such as food wastes or purpose grown crops, kg N yr^{-1} where the system (s) refers exclusively to anaerobic digestion

P = productivity class, high or low, to be considered if using the Tier 1a 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. To consider productivity class P, if using a Tier 1a approach

$Frac_{gasMS(T,S)}$ = fraction of managed manure nitrogen for livestock category T that volatilises as NH_3 and NO_x in the manure management system S

The Tier 1 calculation of N leached and runoff 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 nitrogen leached, in analogy to the approach to estimate nitrogen volatilsation (see Equation 10.26). 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 and manure heaps or composting systems, uncovered and uncontained. In drier climates, runoff losses are smaller than in high rainfall areas and have been estimated in the range from 3 to 6 percent of N excreted (Eghball & Power 1994). Studies by Bierman *et al*. (1999) found nitrogen lost in runoff was 5 to 19 percent of N excreted and 10 to 16 percent leached into soil, while other data show relatively low loss of nitrogen through leaching in solid storage (less than 5 percent 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.

EQUATION 10.27 (UPDATED)
N LOSSES DUE TO LEACHING FROM MANURE MANAGEMENT

$$N_{leaching-MMS} = \sum_{S}\left[\sum_{T,P}\left[\left(\left(N_{(T,P)} \bullet Nex_{(T,P)} \bullet AWMS_{(T,S,P)}\right) + N_{cdg(s)}\right) \bullet Frac_{LeachMS(T,S)}\right]\right]$$

Where:

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

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

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

$N_{cdg(s)}$ = amount of nitrogen from co-digestates added to biogas plants such as food wastes or purpose grown crops, kg N yr^{-1} where the system (s) refers exclusively to anaerobic digestion

P = productivity class, high or low, to be considered if using the Tier 1a 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, for productivity system P, when applicable, dimensionless

$Frac_{LeachMS(T,S)}$ = fraction of managed manure nitrogen for livestock category T that is leached from the manure management system S (from Table 10.22)

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 10.28:

EQUATION 10.28

INDIRECT N_2O 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)$^{-1}$; given in Chapter 11, Table 11.3

The indirect N_2O emissions due to leaching and runoff from Manure Management ($N_2O_{L(mm)}$) are estimated using Equation 10.29:

EQUATION 10.29

INDIRECT N_2O EMISSIONS DUE TO LEACHING FROM MANURE MANAGEMENT

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

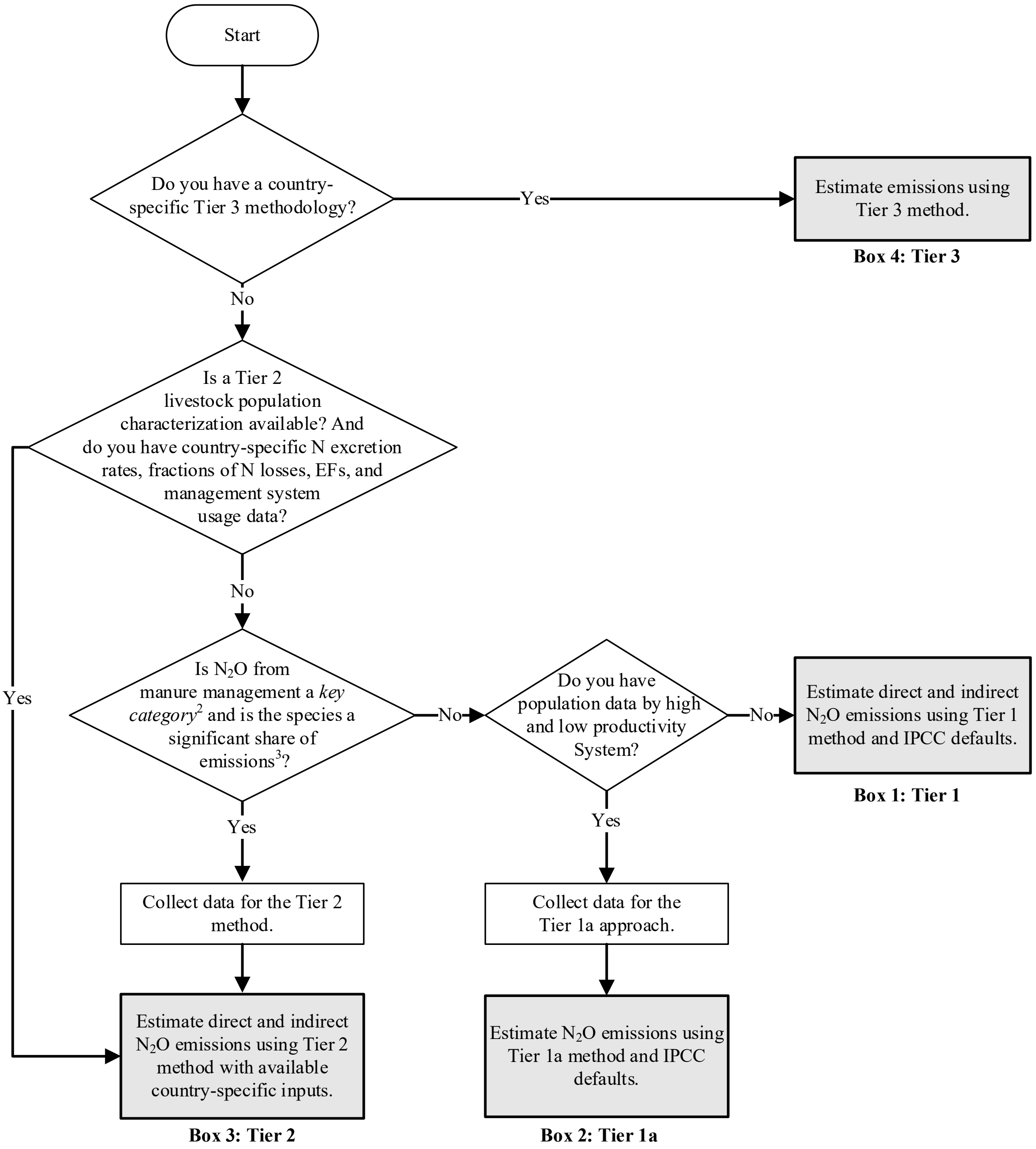
Where:

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

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

EF_5 = emission factor for N_2O emissions from nitrogen leaching and runoff, kg N_2O-N/kg N leached and runoff, given in Chapter 11, Table 11.3

Figure 10.4 (Updated) Decision tree for N_2O emissions from Manure Management(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.

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. 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 as described in Section 10.5.6. 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 NO_x 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 $N_{volatilization-MMS}$ in consistency to the NH_3 and NO_x emissions reported to the UN-ECE.

Tier 3

To reduce uncertainty of the estimates, a Tier 3 method could be developed using advanced or process-based models 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

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 (UPDATED)
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 1a (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 1a approach

Default TAM values are provided in Annex 10A.1, Table 10A.5. 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), it should be kept in mind that the dung is burned, and the urine stays in the field. Generally, 50 percent of the nitrogen excreted is in the dung and 50 percent 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, OPTION 1 (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 daily N intake per head of animal of species/category *T*, kg N animal^{-1} day^{-1}

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

365 = Number of days in a year[6]

EQUATION 10.31A (NEW)
ANNUAL N EXCRETION RATES, OPTION 2 (TIER 2)

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

Where:

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

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

$N_{retention(T)}$ = amount of daily N intake by head of animal of species / category *T*, that is retained by animal of species/category *T*, kg N animal^{-1} day^{-1}

365 = Number of days in a year[6]

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

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[6] Consideration should be taken of periods between production cycles, particularly for animal categories that may have multiple annual growth cycles. For livestock species with a lifetime shorter than one year, the approach suggested by Haenel *et al.* (2018) (see chapters 3.1.2.2.1 to 3.1.2.2.3) and by Rösemann *et al.* (2017) can be considered.

EQUATION 10.32
N INTAKE RATES FOR CATTLE, SHEEP AND GOATS

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

EQUATION 10.32A (NEW)
N INTAKE RATES FOR SWINE AND POULTRY

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

Where:

$N_{\text{int}ake(T,i)}$ =daily N consumed per animal of category *T*, kg N animal^{-1} day^{-1}, per growth stage^{-1} "*i*" when applicable

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 and 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 per day during a specific growth stage "*i*", (kg DMI animal day^{-1})

$CP\%_i$ = percent crude protein in dry matter for growth stage "*i*". (Table 10A.1, Table 10A.2 and Table 10A.3 present default CP% values for all regions)

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

As an example, the intake of N for a growing pig between 32 to 60 kg of body weight with a daily intake of 1.67 kg of a diet containing 18 percent CP would be, applying the above equation, equivalent to 0.05 kg N day^{-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 (UPDATED)
DEFAULT VALUES FOR NITROGEN EXCRETION RATE (KG N (1000 KG ANIMAL MASS)$^{-1}$ DAY^{-1})

Category of animal	**Region**																		
	North America	**Western Europe**	**Eastern Europe**	**Oceania**	**Latin America**			**Africa**			**Middle East**			**Asia**			**India subcontinent**		
					Mean	**High PS**[1]	**Low PS**[1]	**Mean**	**High PS**	**Low PS**	**Mean**	**High PS**	**Low PS**	**Mean**	**High PS**	**Low PS**	**Mean**	**High PS**	**Low PS**
Dairy cattle[3]	0.59	0.54	0.42	0.72	0.39	0.60	0.28	0.44	0.41	0.45	0.50	0.49	0.51	0.44	0.55	0.41	0.65	0.51	0.70
Other cattle[3]	0.40	0.42	0.47	0.46	0.31	0.36	0.29	0.45	0.42	0.44	0.56	0.51	0.59	0.38	0.36	0.39	0.44	0.64	0.41
Buffalo[3]	NA	0.45	0.35	NA	0.41			0.42			0.39			0.44			0.58		
Swine[4]	0.39	0.65	0.63	0.54	0.59	0.55	0.67	0.44	0.33	0.49	0.66	0.67	0.56	0.61	0.54	0.67	0.68	0.63	0.71
Finishing	0.46	0.76	0.77	0.72	0.73	0.69	0.80	0.49	0.39	0.54	0.73	0.75	0.60	0.70	0.63	0.76	0.76	0.74	0.76
Breeding	0.24	0.38	0.36	0.31	0.35	0.32	0.43	0.29	0.21	0.35	0.40	0.41	0.37	0.37	0.32	0.43	0.43	0.37	0.47
Chicken[4]	1.45	0.99	0.96	1.42	1.20	1.13	2.14	1.29	1.16	1.44	1.29	1.27	1.79	1.10	1.00	1.62	1.62	1.48	1.83
Hens >/= 1 yr	1.13	0.87	0.81	1.04	1.17	1.02	2.01	1.20	0.99	1.34	1.11	1.06	1.70	1.00	0.89	1.50	1.65	1.60	1.70
Pullets	0.77	0.58	0.58	0.76	0.95	0.68	2.50	1.29	0.70	1.72	0.85	0.74	2.03	0.83	0.60	1.91	1.63	0.98	2.20
Broilers	1.59	1.14	1.12	1.59	1.23	1.21	2.39	1.40	1.34	1.58	1.43	1.42	1.95	1.35	1.31	1.84	1.58	1.47	2.11
Turkeys[12]	0.74																		
Ducks[12]	0.83																		
Sheep[4]	0.35	0.36	0.36	0.43	0.32														
Goats[5]	0.46	0.46	0.44	0.42	0.34														
Horses and mules and asses[12]	0.30	0.26	0.30	0.30	0.46														

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

	Region																		
	North America	Western Europe	Eastern Europe	Oceania	Latin America			Africa			Middle East			Asia			India sub-continent		
					Mean	High PS[1]	Low PS[1]	Mean	High PS	Low PS	Mean	High PS	Low PS	Mean	High PS	Low PS	Mean	High PS	Low PS
Camels[12]	0.38				0.46														
Ostrich[7,11]	0.36																		
Deer[8,11]	0.67																		
Reindeer[9,11]	0.23																		
Mink and Polecat (kg N head^{-1} yr^{-1})[6,11]	4.59																		
Rabbits (kg N head^{-1} yr^{-1})[10,11]	8.10																		
Fox and Racoon (kg N head^{-1} yr^{-1})[6,11]	12.09																		

[1] High PS and Low PS refer to high- and low productivity systems required for Tier 1a methodology.

[2] NA refers to situations in which these animal categories do not occur in these regions.

[3] Values are derived from diets used in the calculation of enteric fermentation Tier 1 emission factors (Annex 10A.1).

[4] Values are taken from FAO GLEAM databases (FAO 2017).

[5] Calculations are detailed in Annex 10B.3.

[6] Data of Hutchings *et al*. (2001) (as cited in *2006 IPCC Guidelines*).

[7] Nex rate for ostrich in kg N (1000 kg animal mass)$^{-1}$ day^{-1} was calculated taking into account an average value on weight of bird (120 kg) and a rate of nitrogen excretion per head per year (15.6 kgN/head/year). Sources: Velthof (2014); Reis & Oliveira (2008); du Toit *et al*. (2013).

[8] Nex rate for deer in kg N (1000 kg animal mass)$^{-1}$ day^{-1} was calculated taking into account an average value on weight of animal (120 kg) and a rate of nitrogen excretion per head per year (29.32 kgN/head/year). Sources: Danish NIR (Nielsen *et al*. 2018), New Zealand's NIR (Ministry for the Environment 2018).

[9] Nex rate for reindeer in kg N (1000 kg animal mass)$^{-1}$ day^{-1} was calculated taking into account an average value on weight of animal (120 kg) and a rate of nitrogen excretion per head per year (5.75 kgN/head/year).Sources: Danish NIR (Nielsen *et al*. 2018); New Zealand's NIR (Ministry for the Environment 2018).

[10] Nex rate per average doe, including young reproduction stock and males. Sources: Maertens *et al*. (2005); Xiccato *et al*. (2005); Gasco *et al*. (2014); Velthof *et al*. (2015).

[11] The IPCC expert group reviewed the national inventory submissions under the UNFCCC and concluded that common distribution of systems used to manage manure as follows: 80 percent of ostrich'manure is deposited in pasture and in range and 20 percent is managed in solid based systems; deer and reindeer manure deposited mainly in pasture and in range, manure of rabbits and fur-bearing animals is managed mostly in a solid based systems. Hence, countries may apply the same allocation of MMS in the calculation of N_2O emissions from manure stored in manure management systems. However, countries are encouraged to develop a country-specific dataset on MMS used to manage manure generated by these categories of animals.

[12] The values are taken from Table 10.19 of Chapter 10 of Volume 4 of the *2006 IPCC Guidelines*.

TABLE 10.20 (UPDATED)
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)$^{-1}$
Cattle and Buffalo	See values in Annex 10A.1
Sheep	0.10
Goats	0.10
Camels	0.07
Swine	0.30
Horses	0.07
Poultry	0.30

This N retention values apply to non-dairy sheep and goats. For dairy sheep and goats country-specific values are recommended. Values are applied in Equation 10.31, Option 1 for the calculation of annual N excretion.

The uncertainty in these estimates is $\underline{+}50\%$.

Source: *2006 IPCC Guidelines*, Table 10.21.

Tier 2 method for estimating nitrogen excretion for cattle

The total nitrogen retained for cattle is derived as follows:

EQUATION 10.33
N RETENTION 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), or the values reported in Table 10A.1, Table 10A.2 and Table 10A.3 can be used

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), g Protein kg^{-1} animal^{-1} and g Protein MJ^{-1} animal^{-1} respectively

1000 = conversion from g protein to kg protein

NE_g = 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)$^{-1}$

Nitrogen excretion is calculated using Equation 10.31a, Option 2.

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 estimates for at least the pig categories listed in Table 10.1.

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 10.33A (NEW)
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 N animal^{-1} year^{-1})

N_{gain} = amount of N retained in the sow (in kg N animal^{-1} year^{-1}), calculated as (0.025 *FR * Skg)

Where:

0.025 = fraction of N retained in BW, kg N·kg BW gain^{-1}

FR = fertility rate of sows, parturitions·year^{-1}

Skg = is the sum of live weight change of sows from parturition to parturition, kg·head^{-1} and can be calculated from the litter birth weight and number (LITSIZE * Ckg/0.806

Where:

LITSIZE = litter size, heads

Ckg = live weight of piglets at birth, kg·head^{-1}

0.806 = constant to correct for the higher kg N per kg BW gain^{-1} in piglets, fraction)

$N_{weaned\ piglets}$ = amount of N in piglets weaned calculated as in Equation 10.33b (in kg N animal^{-1} year^{-1})

EQUATION 10.33B (NEW)
N RETENTION RATES FOR PIGLETS

$$N_{weaned\ piglets} = 0.025 \bullet LITSIZE \bullet FR \bullet \frac{(Wkg - Ckg)}{0.98}$$

Where:

0.025 = fraction of N retained in BW, kg N·kg BW gain^{-1}

LITSIZE = litter size, heads

FR = fertility rate of sows, parturitions·year^{-1}

Wkg = live weight of piglet at weaning age, kg·head^{-1}

Ckg = live weight of piglets at birth, kg·head^{-1} and

0.98 = protein digestibility as fraction (FAO, 2017)

TABLE 10.20A (NEW)
CALCULATION OF N RETENTION IN BREEDING SWINE FROM DIFFERENT PRODUCTION SYSTEMS, AN EXAMPLE

System	**Ckg**	**Wkg**	**FR**	**LITSIZE**	**Sows Ngain**[a]	**Piglets Ngain**
	kg	kg		heads	kg N animal^{-1} year^{-1}	kg N animal^{-1} year^{-1}
Low Productivity	0.8	6.5	1.7	9.1	0.92	2.25
High Productivity	1.2	7.0	2.1	9.2	1.38	2.85

[a] For this example, a live weight change of young sows from parturition to parturition of 12.5 kg was assumed.

The value of Skg is derived from national statistics on the average litter size and birth weight of piglets, factors that vary based on national production systems. Further, gilts will typically be mated at 125 – 140 kg of body weight, and continue to grow over several reproductive cycles to a mature weight of approximately 200 kg of body weight. The N excretion by breeding sows (Equation 10.33B) should also take into account that the sow will gain between 10 to 15 kg of body weight during the first four or five reproductive cycles (Chiba 2009). Inventory compilers are advised to: (a) use data that best describe their country production practices and/or genetic stocks employed for estimates of litter size and birth weight; (b) estimate the proportion of the breeding animals that are not at mature weight and consider the growth of these animals in their estimate of Skg. The weight of the placenta and other products of conception are not included in Tier 2 calculations as they are discarded at parturition. Countries that are able to track nitrogen in conception products may choose to do so through country specific methods

The daily N retention can be calculated by dividing the result of equation 10.33a by the total number of days in the gestational and weaning periods to provide a daily N retention in kg N day^{-1}. Nitrogen excretion is calculated using Equation 10.31a, Option 2.

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

EQUATION 10.33C (NEW)
N RETENTION RATES FOR GROWING PIGS

$$N_{retention} = \sum_{i} (BW_{Final_{(i)}} - BW_{Initial_{(i)}}) \bullet N_{gain_{(i)}}$$

Where:

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

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

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

$N_{gain_{(i)}}$ = fraction of N retained at a given BW per defined growth stage *(i)*, 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 kg N kg BW gain^{-1}

These should be summed over the different production stages[7]. Daily N retention is calculated by dividing the total N retention by the length of the production period from weaning to slaughter. Nitrogen excretion is calculated using Equation 10.31a, Option 2.

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[7] It should be noted that factors other than physiological stage can affect nitrogen retention, including body weight (Pettey *et al*. 2015), sex and genetic line (Wiseman *et al*. 2007).

TABLE 10.20B (NEW)
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} was calculated for a given BW as $N_{gain} = -0.004 \ln(BW) + 0.0381$. Based on Shields *et al.* (1983) and further adjusted based on data from Poulsen & Kristensen (1998) and FAO (2017).

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.

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 faeces (Boonsinchai *et al.* 2016). Different categories of animals (for meat or eggs) 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 at least the poultry categories listed in Table 10.1.

In estimating nitrogen excretion, the nitrogen balance approach is also very useful, for which information on 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 retention by layer type hens is as follows (Poulsen & Kristensen 1998):

EQUATION 10.33D (NEW)
N RETENTION RATES FOR LAYER TYPE HENS

$$N_{retention,c} = \left[N_{LW} \bullet WG_c + \left(\frac{N_{EGG} \bullet EGG}{1000} \right) \right]$$

Where:

$N_{retention,c}$ = daily nitrogen retention by animal in cohort c, kg N·head^{-1}day^{-1}

N_{LW} = average content of nitrogen in live weight, kg N·kg head^{-1}. Default value of 0.028 is used

WG_c = average daily weight gain for cohort c, kg·head^{-1}·day^{-1}

N_{EGG} = average content of nitrogen in eggs, kg N·kg egg^{-1}. Default value of 0.0185 is used

EGG = egg mass production, g egg·head^{-1} day^{-1}

A suitable approach to estimate annual nitrogen retention by pullets and broilers is as follows (Poulsen & Kristensen 1998):

EQUATION 10.33E (NEW)
DAILY N RETENTION RATES FOR PULLETS OR BROILERS

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

Where:

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

BW_{Final} = 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 fraction of N (kg) retained per kg BW gain

$production\_period$ = length of time from chick to slaughter (days)

Default value for N_{gain} = 0.028 based on data from Poulsen & Kristensen (1998) and FAO (2017)

Nitrogen excretion is calculated using Equation 10.31a, Option 2.

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 and anaerobic lagoons 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, $Frac_{GasMS}$, and leaching/runoff, $Frac_{LeachMS}$), 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.

N_2O emissions from multiple Manure Management systems

Consistent with CH_4 manure management, if manure is managed in multiple systems, by default, manure emission factors should be allocated to the dominant storage systems; But a country specific emission factor could be developed considering the emissions originating from all other systems used in storage prior to field applicaton.

A number of combinations are possible and as was the case with methane emissions from manure management, it is beyond the scope of these guidelines to provide guidance for all possibilities but common examples include: i.) manure flushed from a dairy freestall barn to an anaerobic lagoon that first pass through a solids separation unit where some of the manure nitrogen is removed and managed as a solid; ii.) pit storage that is flushed to a larger holding tank; iii.) solid manure pack that is allowed to accumulate, and periodically transferred to heaps.

In these cases, emissions could be calculated based on Tier 2 factors from the separate manure fractions and weighted based on the duration of storage in the different systems. Emission factors as developed and reported in these guidelines are assumed to be for a full year of N within a given manure management system. The application of a country-specific, staged emission factor would require estimates of sub-annual emissions based on manure residency times in each stage. Further, this type of approach should consider the application of a full mass balance approach and likewise consider N loss at each stage.

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).

Consistency should be maintained for the treatment of nitrogen flows throughout all agricultural emission calculations, including managed soils as outlined in Section 10.5.4[8].

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[8] As discussed in Section 10.5.4, N losses from housing and storage have to be subtracted before the calculation of N_2O emissions (direct and indirect) from agricultural soils.

TABLE 10.21 (UPDATED)
DEFAULT EMISSION FACTORS FOR DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT[24]

System	**Definition**		**EF_3 [kg N_2O-N (kg nitrogen excreted)$^{-1}$]**
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[5]	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
Solid storage[2,4,6]	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
Solid storage- Covered/compacted[4,7]	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
Solid storage- Bulking agent addition[4,8]	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
Solid storage – Additives[4,8]	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 reduces CH_4 emissions.		0.005
Dry lot[9]	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
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 [9] natural crust cover	0.005
		Without [10] natural crust cover	0
		Cover[11]	0.005
Uncovered[12] 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
Pit storage[13] 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
Anaerobic[14] 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

TABLE 10.21 (UPDATED) (CONTINUED)
DEFAULT EMISSION FACTORS FOR DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT[24]

System	**Definition**		**EF_3 [kg N_2O-N (kg nitrogen excreted)$^{-1}$]**
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[15]	0.01
		Active mixing [16]	0.07
Composting - In-Vessel[3,17]	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.		0.006
Composting - Static Pile[3] (Forced aeration)[4,18]	Composting in piles with forced aeration but no mixing.		0.010
Composting - Intensive Windrow[3,19] (Frequent turning)	Composting in windrows with regular turning for mixing and aeration.		0.005
Composting- Passive windrow (infrequent turning) [4, 20]	Composting in windrows with infrequent turning for mixing and aeration.		0.005
Poultry manure with litter[21]	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
Poultry manure without litter[21]	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

TABLE 10.21 (UPDATED) (CONTINUED)
DEFAULT EMISSION FACTORS FOR DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT[24]

System	Definition		EF_3 [kg N_2O-N (kg nitrogen excreted)$^{-1}$]
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[22]	0.01
		Forced aeration systems[23]	0.005

[1] Also see AFRC (1995) and Dustan (2002), which compiled information from some of the original references cited.

[2] 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.

[3] 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.

[4] Sources and assumptions to calculate N_2O EF for Solid storage systems with/without treatments and composting (static pile and passive windrows) are detailed in Annex 10B.7.

[5] *2006 IPCC Guidelines*, Table 10.21.

[6] Expert judgement based on Pardo *et al*. (2015). Median of N_2O emissions from farm-scale collected studies.

[7] Expert judgement based on Pardo *et al*. (2015). Emissions in the same range than solid storage.

[8] Expert judgement based on Pardo *et al*. (2015). Estimated reduction of 50% N_2O emissions due to bulking agent addition.

[9] Judgement of IPCC Expert Group in combination with Kulling *et al*. (2003).

[10] 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 & 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.

[11] 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 natural crust cover.

[12] 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 & 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.

[13] Judgement of IPCC Expert Group in combination with the following studies: Amon *et al*. (2001), Kulling *et al*. (2003), and Sneath *et al*. (1997).

[14] The emission mainly from storage of digestate.

[15] 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 *et al*. (2006); Moitzi *et al*. (2007); Clemens *et al*. (2006). Average value based on Moller *et al*. (2000), Sommer & Møller (2000), Amon *et al*. (1998a); Amon *et al*. (1998b), and Nicks *et al*. (2003).

[16] 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.

[17] Judgement of IPCC Expert Group. Expected to be similar to static piles.

[18] Expert judgement based on Pardo *et al*. (2015). Emissions in the same range than solid storage.

[19] Assuming similar range to passive windrow.

[20] Expert judgement based on Pardo *et al*. (2015). Median of N_2O emissions from farm-scale collected studies and estimated reduction of 50% due to bulking agent addition.

[21] Judgement of IPCC Expert Group based on the high loss of ammonia from these systems, which limits the availability of nitrogen for nitrification/denitrification.

[22] 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.

[23] 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.

[24] Uncertainties for emission factors are defined as varying by a factor of 2 (±100%).

10.5.3 Choice of activity data

No refinement.

10.5.4 Coordination with reporting for N_2O emissions from managed soils

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

A significant proportion of the total nitrogen excreted by animals in managed systems (i.e., all livestock except those in pasture and grazing conditions) is lost prior to final application to managed soils or 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 N_2O), direct conversion to N_2O, or losses as inert molecular nitrogen (N_2).

nitrogen in manure is present both as organic nitrogen (Norg) and mineral nitrogen, of which the majority consists of '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 volatilisation fraction $Frac_{GASMS}$ listed in Table 10.22 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. 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 (UPDATED)
MANAGED MANURE N AVAILABLE FOR APPLICATION TO MANAGED SOILS, FEED, FUEL OR CONSTRUCTION USES

$$N_{MMS_{Avb}} = \sum_{S} \left\{ \sum_{(T)} \left[\begin{array}{l} \left[\left(N_{(T)} \bullet Nex_{(T)} \bullet AWMS_{(T,S)} + N_{cdg} \right) \bullet \left(1 - Frac_{LossMS_{(T,S)}} \right) \right] + \\ + \left[N_{(T)} \bullet AWMS_{(T,S)} \bullet N_{beddingMS_{(T,S)}} \right] \end{array} \right] \right\}$$

Where:

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

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

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

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

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

$N_{beddingMS_{(T,S)}}$ = 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_{cdg} = 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 10.34A (NEW)
FRACTION OF MANAGED MANURE N LOST PRIOR TO APPLICATION TO MANAGED SOILS FOR THE PRODUCTION OF FEED, FUEL OR FOR CONSTRUCTION USES

$$FRAC_{LOSS_{MS_{(T,S)}}} = FRAC_{GAS_{MS_{(T,S)}}} + FRAC_{LEACHS_{MS_{(T,S)}}} + FRAC_{N_2MS_{(S)}} + EF_{3_{(S)}}$$

Where:

$FRAC_{LOSS_{MS_{(T,S)}}}$ = total fraction of managed manure nitrogen for livestock category *T* that is lost in the manure management system *S*

$FRAC_{GAS_{MS_{(T,S)}}}$ = fraction 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 10.22)

$FRAC_{LEACHS_{MS_{(T,S)}}}$ = fraction of managed manure nitrogen for livestock category *T* that is lost in the manure management system *S* by leaching or run-off (see Table 10.22)

$FRAC_{N_2MS_{(S)}}$ = fraction of managed manure nitrogen that is lost in the manure management system *S* as N_2 (see Equation 10.34b)

$EF_{3_{(S)}}$ = emission factor for direct N_2O emissions from manure management system *S*; in this case considered dimensionless (see Table 10.21)

The amount of managed nitrogen that is lost by denitrification to N_2 can be obtained as a ratio of N_2:N_2O emissions. Webb & 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 be calculated according to Equation 10.34B.

EQUATION 10.34B (NEW)
ESTIMATION OF $FRAC_{N2MS}$

$$Frac_{N_2MS_{(S)}} = R_{N_2\left(N_2O\right)} \bullet EF_{3(S)}$$

Where:

$FRAC_{N_2MS_{(S)}}$ = fraction of managed manure nitrogen for livestock category T that is lost as N_2 in the manure management system S,

$EF_{3_{(S)}}$ = emission factor for direct N_2O emissions from manure management system S in the country, kg N_2O-N (kg N)$^{-1}$ in manure management system S

$R_{N_2(N_2O)}$ = Ratio of $N_2 : N_2O$ emissions. The default value of $R_{N2(N2O)}$ is 3 kg N_2-N (kg N_2O-N)$^{-1}$ (see Table 10.23)

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 "3.C.4 - Direct N_2O emissions from managed soils" (F_{CR} - volume 11, chapter 11, section 11.2.1.3), "3.C.1 - Biomass burning" (volume 4, chapter 5, section 5.2.4 Non-CO_2 greenhouse gas emissions from biomass burning) and "4.C.2 - Open burning of waste" (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. This is important to eliminate the possibility of double counting.

nitrogen content of co-digestates should be consistent in quantity and definition with the co-digests defined information in guidance on the use of co-digestates in “Energy” found in Volume 2, Chapter 2, Section 2.3.3.4 and “Waste”, Volume 5, Chapters 2 and 3, Sections 2.3.2 and 3.2.

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

Table 10.23 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 10.34b to calculate default N_2 emission 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. Additional details are available in the EMEP/EEA air pollutant emission inventory Guidebook 2016 (EEA 2016, Chapter 3B and 3.D and Annex A1.4).

TABLE 10.22 (UPDATED)
DEFAULT VALUES FOR NITROGEN LOSS FRACTIONS 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$_{leach\_MS}$
Uncovered anaerobic lagoon		0.40 (0.25 – 0.75)	0	0.35 (0.20 – 0.80)	0	0.40 (0.25 – 0.75)	0	0.35 (0.20 – 0.80)	0	0.35 (0.20 – 0.80)	0
Liquid/Slurry	With natural crust cover	0.30 (0.09 – 0.36)	0	0.30 (0.09 – 0.36)	0	no data	0	0.30 (0.09 – 0.36)	0	0.09	0
	Without natural crust cover	0.48 (0.15 – 0.60)	0	0.48 (0.15 – 0.60)	0	0.40 (0.25 – 0.75)	0	0.48 (0.15 – 0.60	0	0.15	0
	With cover	0.10 (0.03 – 0.12)	0	0.10 (0.03 – 0.12)	0	0.08 (0.05-0.15)	0	0.10 (0.03 – 0.12)	0	0.03	0
Pit storage below animal confinements		0.25 (0.15 – 0.30)	0	0.28 (0.10 – 0.40)	0	0.28 (0.10 – 0.40)	0	0.25 (0.15 – 0.30)	0	0.25 (0.15 – 0.30)	0
Daily spread		0.07 (0.05 – 0.60)	0	0.07 (0.05 – 0.60)	0	0.07 (0.05 – 0.60)	0	0.07 (0.05 – 0.60)	0	0.07 (0.05 – 0.60)	0
[7]Solid storage	Covered/compacted	0.22 (0.04 – 0.26)	0	0.14 (0.02 – 0.17)	0	0.20 (0.04 – 0.24)	0	0.22 (0.03 – 0.26)	0	0.05 (0 – 0.07)	0
	Bulking agent addition	0.58 (0.11 – 0.70)	0.02	0.38 (0.06 – 0.46)	0.02	0.54 (0.10 – 0.65)	0.02	0.58 (0.08 – 0.70)	0.02	0.15 (0.06 – 0.18)	0.02
	Additives	0.17 (0.03 – 0.21)	0.02	0.11 (0.01 – 0.14)	0.02	0.16 (0.03 – 0.20)	0.02	0.17 (0.02 – 0.21)	0.02	0.04 (0.01 – 0.05)	0.02
	-	0.45 (0.10 – 0.65)	0.02	0.30 (0.10 – 0.40)	0.02	0.40 (0.12 – 0.60)	0.02	0.45 (0.10 – 0.65)	0.02	0.12 (0.05 – 0.20)	0.02
[4]Dry lot		0.45 (0.10 – 0.65)	0.035 (0 – 0.07)	0.30 (0.20 – 0.50)	0.035 (0 – 0.07)	NA	NA	0.30 (0.20 – 0.50)	0.035 (0 – 0.07)	0.30 (0.20 – 0.50)	0.035
[3]Anaerobic digester		0.05 – 0.50	0	0.05 – 0.50	0	0.05 – 0.50	0	0.05 – 0.50	0	0.05 – 0.50	0

TABLE 10.22 (UPDATED) (CONTINUED)
DEFAULT VALUES FOR NITROGEN LOSS FRACTIONS 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**	
		$^1Frac_{Gas\_MS}$	**$^{2,5}Frac_{leach\_MS}$**	**$Frac_{Gas\_MS}$**	**$^{2,5}Frac_{leach\_MS}$**	**$Frac_{Gas\_MS}$**	**$^{2,5}Frac_{leach\_MS}$**	**$Frac_{Gas\_MS}$**	**$^{2,5}Frac_{leach\_MS}$**	**$Frac_{Gas\_MS}$**	**$^{2,5}Frac_{leach\_MS}$**
Burned for fuel or as waste		NA									
Cattle and swine deep bedding		0.40 (0.10 – 0.60)	0.035	0.25 (0.10 – 0.30)	0.035	NA		0.25 (0.10 – 0.30)	0.035	NA	
[7]Composting	In-Vessel	0.60 (0.12-0.65)	0	0.45 (0.07-0.54)	0	0.60 (0.12-0.65)	0	0.60 (0.12-0.65)	0	0.18 (0.04-0.21)	0
	Static Pile	0.65 (0.14-0.70)	0.06	0.50 (0.07-0.60)	0.06	0.65 (0.14-0.70)	0.06	0.65 (0.14-0.70)	0.06	0.20 (0.05-0.24)	0.06
	Intensive Windrow	0.65 (0.14-0.70)	0.06	0.50 (0.07-0.60)	0.06	0.65 (0.14-0.70)	0.06	0.65 (0.14-0.70)	0.06	0.20 (0.05-0.24)	0.06
	Passive Windrow	0.60 (0.12-0.65)	0.04	0.45 (0.07-0.54)	0.04	0.60 (0.12-0.65)	0.04	0.60 (0.12-0.65)	0.04	0.18 (0.04-0.21)	0.04
Poultry manure	with litter	NA				0.40 (0.10 – 0.60)	0	NA			
	without litter	NA				0.48 (0.15 – 0.60)	0	NA			
[3]Aerobic treatment	Natural aeration systems	no data[6]	0	no data[6]	0	no data[6]	0	no data[6]	0	no data[6]	0
	Forced aeration systems	0.85 (0.27 – 1)	0	0.85 (0.27 – 1)	0	no data[6]	0	0.85 (0.27 – 1)	0	0.27	0

Source: The values are mainly from *2006 IPCC Guidelines* but other sources and analyses are 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.

[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 0.5 of nitrogen. The lower range of 0.05 losses is valid for digestate with a high dry matter content and a cover. The ranges indicated also apply to co-digestates. It is advised to use the liquid slurry without cover for uncovered digestate.

[4] Uncertainty range is 0 to 0.07. Leaching values are dependant on annual rainfall. Country-specific data should be developed if leaching is observed to be a significant source based on 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. Country specific values should be used, or a surrogate should be selected from the table and justified based on consideration of factors controlling rates of volatilisation in the management system.

[7] Sources and assumptions to calculate NH_3 volatilization and N leaching/run-off for Solid storage and composting (static pile and passive windrows) systems are detailed in Annex 10B.7.

TABLE 10.23 (NEW)
DEFAULT VALUE FOR MOLECULAR NITROGEN (N_2) LOSS FROM MANURE MANAGEMENT

Factor	Unit	Value	Range
$R_{N2(N2O)}$	kg N_2-N (kg N_2O-N)$^{-1}$	3[1]	1-10

[1] Webb & Misselbrook (2004)

10.5.5 Uncertainty assessment

No refinement.

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

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

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

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

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

Activity data check

The inventory agency should review livestock data collection methods, in particular checking that livestock subspecies data were collected and aggregated correctly with consideration for the duration of production cycles. The data should be cross-checked with previous years to ensure the data are reasonable and consistent with the expected trend. Inventory agencies should document data collection methods, identify potential areas of bias, and evaluate the representativeness of the data.

Manure management system allocation should be reviewed on a regular basis to determine if changes in the livestock industry are being captured. Conversion from one type of management system to another, and technical modifications to system configuration and performance, should be captured in the system modelling for the affected livestock.

National agricultural policy and regulations may have an effect on parameters that are used to calculate manure emissions, and should be reviewed regularly to determine what impact they may have. For example, guidelines to reduce manure runoff into water bodies may cause a change in management practices, and thus affect the N distribution for a particular livestock category. Consistency should be maintained between the inventory and ongoing changes in agricultural practices.

If using country-specific data for $Nex_{(T)}$ and $MS_{(T,S)}$, the inventory agency should compare these values to the IPCC default values. Significant differences, data sources, and methods of data derivation, should be documented.

The nitrogen excretion rates, whether default or country-specific values, should be consistent with feed intake data as determined through animal nutrition analyses.

Review of emission factors

The inventory agency should evaluate how well the implied N_2O emission factors and nitrogen excretion rates compare with alternative national data sources and with data from other countries with similar livestock practices. Significant differences should be investigated.

If using country-specific emission factors, the inventory agency should compare them to the default factors and note differences. The development of country-specific emission factors should be explained and documented, and the results peer-reviewed by independent experts.

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

External review

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

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

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

- Emissions from the manure management system for pasture, range, and paddock are to be reported under the IPCC source category N_2O emissions from managed soils because this manure is deposited directly on soils by the livestock.
- Emissions 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 animals, or under manure management if collected in housed systems.

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 10A.5 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 estimates that might become inaccurate when national methodologies for upstream flows are used. For example, Equation 10A.13-10A.16 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 increases losses of NH_3, modifies the ratio of inorganic to organic N and increases 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). In this case, methodologies may want to consider, a correction factor that is consistent with the national method for NH_3 emissions and takes into account the forms of nitrogen that are stored, transferred and lost during these processes.

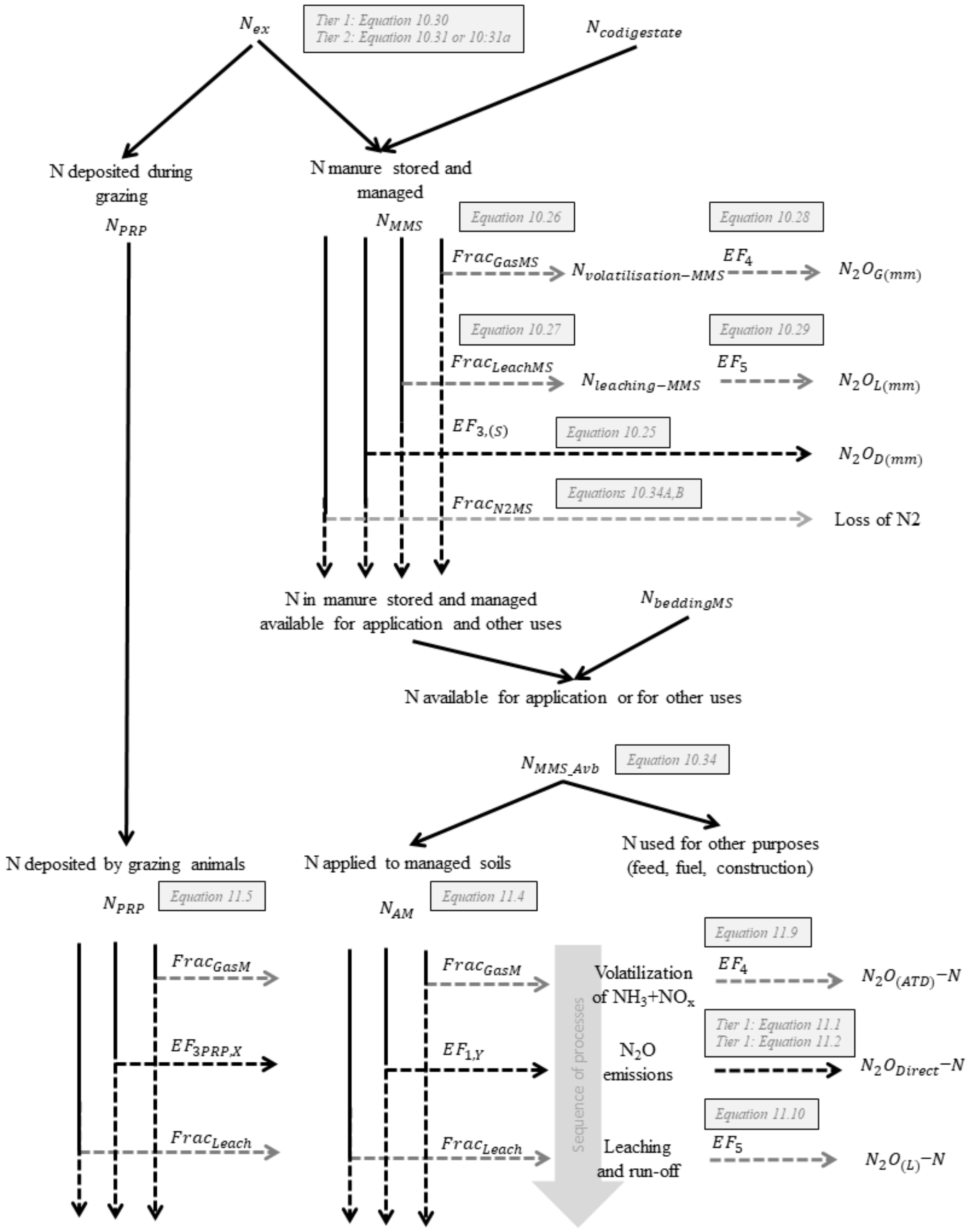
An illustration of N flows through animal and crop production systems is given in Figure 10.5. The figure follows the flow of nitrogen, starting from excretion of nitrogen by animals through livestock and crop production systems down to direct or indirect emissions of N_2O. For each flow shown in Figure 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.

Symbols are defined under the equations in Chapter 10 and 11 and in Annex 10A.5 of Chapter 10. In this Figure all flows denoted with N are averaged annual N flows per head of livestock species/category [kg N animal^{-1} yr^{-1}] or annual N input via co-digestates [kg N 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+NO_x and only thereafter emissions of N_2O and N leaching. This is not reflected in the equations proposed for Tier 1 methodology.

Figure 10.5 (New) **Processes leading to the emission of gaseous N species from manure**



10.5.7 Use of worksheets

No refinement.

Annex 10A.1 Data underlying methane default emission factors for enteric fermentation, volatile solids and nitrogen excretion and retention fractions for Cattle and Buffalo

This annex presents the data used to develop the default emission factors for methane emissions from Enteric Fermentation and Manure Management, Volatile solid and nitrogen excretion rates, and nitrogen retention fraction. The Tier 2 method was implemented with these data to estimate the default Tier 1 emission factors and rates for cattle and buffalo.

This annex also presents the data used to develop the volatile solid estimates used for methane emissions from manure management methane and for nitrogen excretion rates for cattle and buffaloes. The Tier 2 method was implemented with these data.

The literature source for these values are presented in Annex 10B.1 and spreadsheets with raw data for cattle and buffalo compiled for this refinement is available as supplemental material.

TABLE 10A.1 (NEW)
DATA FOR ESTIMATING TIER 1 AND TIER 1A ENTERIC FERMENTATION CH_4 EMISSION FACTORS, VOLATILE SOLID EXCRETION AND N EXCRETION RATES, AND N RETENTION FRACTION RATES FOR DAIRY CATTLE

Regions[7]	Weight, kg	Weight gain, kg/day	Feeding situation	Milk yield[1], kg/day	Fat content of milk, %	Protein content of milk, %	Work, hrs/day	% Pregnant	Digestibility of Feed, %	CP in diet, %	CH_4 conversion, %[2]	Day weighted population mix, %	Enteric fermentation EF, kg CH_4/head/year	kg VS (1000 kg animal mass^{-1}) day^{-1}	kg Nex (1000 kg animal mass^{-1}) day^{-1}	Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$
North America	650	0	Stall Fed	28.0	3.7	3.2	0	90	71	16.7	5.8[6]	100	138	9.2	0.59	0.27
Western Europe	600	0	Stall Fed	20.3	4.2	3.2	0	90	71	16.1	6.3	100	126	8.4	0.54	0.24
Eastern Europe	550	0	Stall Fed	10.9	3.9	3.2	0	85	70	15.1	6.5	100	93	6.7	0.42	0.19
Oceania[3]	488	0	Pasture/Range	12.1	4.8	3.7	0	92	77	22.3	6.5	100	93	6.0	0.72	0.17
Latin America	508	0	Pasture/Range	5.6	4.0	3.2	0	70	65	12.7	6.5	100	87	7.9	0.39	0.12
High productivity systems	520	0	Pasture/Range	9.3	4.0	3.1	0	72	65	17.0	6.5	38	103	9.0	0.60	0.13
Low productivity systems	500	0	Pasture/Range	3.4	4.0	3.2	0	68	65	10.0	6.5	62	78	7.1	0.28	0.11
Asia	386	0	Stall Fed	8.9	3.9	3.2	0	70	66	13.5	6.5	100	78	9.0	0.44	0.20
High productivity systems	485	0	Stall Fed	13.8	4.1	3.1	0	80	70	16.5	6.3	24	96	8.1	0.55	0.20
Low productivity systems	355	0	Stall Fed	7.3	3.9	3.2	0	67	65	12.6	6.5	76	71	9.2	0.41	0.20
Africa	260	0	Stall Fed[5]	3.5	4.3	3.6	0	54	51	8.7	6.5	100	76	18.2	0.44	0.15
High productivity systems	250	0	Stall Fed	5.8	4.3	3.6	0	57	50	7.8	6.5	49	86	21.7	0.41	0.24
Low productivity systems	270	0	Pasture/Range	1.2	4.3	3.6	0	52	51	9.6	6.5	51	66	15.2	0.45	0.05
Middle East	349	0	Stall Fed[5]	5.9	4.1	3.5	0	52	62	13.6	6.5	100	76	10.7	0.50	0.16
High productivity systems	510	0	Stall Fed	10.6	3.5	3.2	0	55	65	15.8	6.5	33	94	8.4	0.49	0.18
Low productivity systems	270	0	Pasture/Range	3.6	4.5	3.7	0	50	60	12.5	6.5	67	62	11.8	0.51	0.13

TABLE 10A.1 (NEW) (CONTINUED)
DATA FOR ESTIMATING TIER 1 AND TIER 1A ENTERIC FERMENTATION CH_4 EMISSION FACTORS, VOLATILE SOLID EXCRETION AND N EXCRETION RATES, AND N RETENTION FRACTION RATES FOR DAIRY CATTLE

Regions[7]	**Weight, kg**	**Weight gain, kg/day**	**Feedingi situation**	**Milk yield**[1]**, kg/day**	**Fat content of milk, %**	**Protein content of milk, %**	**Work, hrs/day**	**% Pregnant**	**Digestibility of Feed, %**	**CP in diet, %**	**CH_4 conversion, %**[2]	**Day weighted population mix, %**	**Enteric fermentation EF, kg CH_4/head/year**	**kg VS (1000 kg animal mass^{-1}) day^{-1}**	**kg Nex (1000 kg animal mass^{-1}) day^{-1}**	**Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$**
Indian subcontinent	285	0	Pasture/Range[5]	5.2	4.2	3.7	0	42	57	14.3	6.5	100	73	14.1	0.65	0.14
High productivity systems	350	0	Stall Fed	7.1	4.0	3.6	0	50	65	15.5	6.5	23	70	9.1	0.51	0.18
Low productivity systems	265	0	Pasture/Range	4.6	4.2	3.7	0	40	55	14.0	6.5	77	74	16.1	0.70	0.13

[1] The value represent milk yield in kg per day during the whole year.

[2] Y_m values are consist with those reported in Table 10.12.

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

[4] Data of Latin America, Asia, Africa, Middle East and Indian subcontinent were estimated as weighted average by taken into account parameter values related to low- and high-production systems and livestock population structure of low and high productivity systems.

[5] As Feeding Situation corresponding to high productivity systems is defined as Stall Fed, but for low productivity systems as Pasture/Range, a weigted activitiy coefficient was applied to estimate Net energy for activity.

[6] Y_m is a weighted annual value using the high productivity value of 5.7 from Table 10.12 for the lactating period of 305 days and the value of 6.3 for the dry period (60 days).

[7] Scientific articles and reports consulted to derive peformance parameters of dairy and non-dairy cattle are listed in Annex 10B.1.

TABLE 10A.2 (NEW)
DATA FOR ESTIMATING TIER 1 ENTERIC FERMENTATION CH_4 EMISSION FACTORS, VOLATILE SOLID AND NITROGEN EXCRETION RATES, AND N RETENTION FRACTION FOR OTHER CATTLE

Regions[4,5]	**Weight, kg**	**Weight gain, kg/day**	**Feeding Situation**	**Milk yield, kg/day**[1]	**Fat content of milk, %**	**Protein content of milk, %**	**Work, hrs/day**	**Pregnant, %**	**Digestibility of feed, %**	**CP in diet, %**	**CH_4 Conversion, %**[2]	**Day weighted population mix, %**	**Enteric fermentation EF, CH_4 kg/head/yr**	**kg VS (1000 kg animal mass^{-1}) day^{-1}**	**kg Nex (1000 kg animal mass^{-1}) day^{-1}**	**Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$**
North America																
Mature Females	580		Pasture/Range	3.0	4.0	3.5		80	62	12.0	7.0	35	98	7.7	0.35	0.07
Mature Males	820		Pasture/Range						62	12.0	7.0	2	98	5.4	0.27	0.00
Calves on milk	125	1.0	Pasture/Range						95	16.0	0.0	16	0	1.9	0.35	0.42
Calves on forage	215	1.0	Pasture/Range						65	13.0	6.3	8	59	12.8	0.63	0.16
Growing heifers/steers	300	0.9	Pasture/Range						62	12.0	6.3	17	67	11.3	0.48	0.14
Replacement/growing	400	0.5	Pasture/Range						62	12.0	7.0	11	73	8.3	0.39	0.07
Feedlot cattle	500	1.4	Stall Fed						75	14.0	3.0	11	37	5.4	0.39	0.13
Western Europe																
Mature Males	600		Pasture/Range						60	14.7	7.0	22	81	6.5	0.38	0.00
Replacement/growing	400	0.4	Pasture/Range						65	16.5	6.3	55	57	6.7	0.47	0.04
Calves on milk	230	0.3	Stall fed						95	17.1	0.0	15	0	0.9	0.28	0.10
Calves on forage	230	0.3	Pasture/Range						73	16.5	6.3	8	32	5.2	0.45	0.06
Eastern Europe																
Mature Females	500		Pasture/Range	3.0	4.2	3.7		80	70	15.1	6.3	39	67	5.5	0.39	0.08
Mature Males	600		Pasture/Range						65	14.2	6.3	9	65	5.1	0.32	0.00
Replacement/growing	350	0.4	Pasture/Range						65	14.2	6.3	27	53	7.2	0.43	0.05
Calves on forage	180	0.7	Pasture/Range						65	14.3	6.3	25	46	12.1	0.68	0.12

TABLE 10A.2 (NEW) (CONTINUED)
DATA FOR ESTIMATING TIER 1 ENTERIC FERMENTATION CH_4 EMISSION FACTORS, VOLATILE SOLID AND NITROGEN EXCRETION RATES, AND N RETENTION FRACTION FOR OTHER CATTLE

Regions[4,5]	Weight, kg	Weight gain, kg/day	Feeding Situation	Milk yield, kg/day[1]	Fat content of milk, %	Protein content of milk, %	Work, hrs/day	Pregnant, %	Digestibility of feed, %	CP in diet, %	CH_4 Conversion, %[2]	Day weighted population mix, %	Enteric fermentation EF, CH_4 kg/head/yr	kg VS (1000 kg animal mass^{-1}) day^{-1}	kg Nex (1000 kg animal mass^{-1}) day^{-1}	Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$
Oceania[3]																
Mature Females	416		Pasture/ Range	1.7	4.8	3.7		81	61	14.0	7.0	45	76	8.5	0.46	0.05
Mature Males	467		Pasture/ Range						62	14.0	7.0	25	64	6.3	0.36	0.00
Young	185	0.41	Pasture/ Range						61	14.0	7.0	30	43	10.9	0.55	0.10
Latin America																
Mature Females	435		Pasture/Range	2.0	4.3	3.5		63	59	9.5	7.0	36	81	9.0	0.31	0.07
Mature Males	582		Pasture/Range						59	9.8	7.0	2	81	6.8	0.26	0.00
Growing heifers/steers	240	0.35	Pasture/Range						61	9.8	7.0	22	47	9.3	0.33	0.11
Replacement/growing	302	0.34	Pasture/Range						60	9.6	7.0	18	57	9.0	0.32	0.08
Calves on milk	66	0.35	Pasture/Range						95	9.5	0.0	10	0	1.8	0.16	0.50
Calves on forage	160	0.35	Pasture/Range						61	10.0	7.0	10	39	11.5	0.40	0.13
Feedlot cattle	460	0.90	Stall Fed						74	14.0	4.0	1	39	4.8	0.35	0.10
Asia																
Mature Females	376		Stall Fed	1.5	4.7	3.3	1.1	50	61	10.6	7.0	27	65	8.0	0.33	0.06
Mature Females - grazing	305		Pasture/Range	1.4	4.7	3.3		65	59	10.0	7.0	9	54	10.0	0.36	0.06
Mature Males	501		Stall Fed				1.1		57	10.1	7.0	15	72	7.3	0.27	0.00
Mature Males - grazing	430		Pasture/Range						57	10.0	7.0	6	68	8.1	0.30	0.00
Growing/Replacement[6]	207	0.28	Pasture/Range						61	10.5	7.0	25	44	10.1	0.39	0.07
Calves on forage6	90	0.36	Pasture/Range						62	10.7	6.3	18	26	15.0	0.56	0.16

TABLE 10A.2 (NEW) (CONTINUED)
DATA FOR ESTIMATING TIER 1 ENTERIC FERMENTATION CH_4 EMISSION FACTORS, VOLATILE SOLID AND NITROGEN EXCRETION RATES, AND N RETENTION FRACTION FOR OTHER CATTLE

Regions[4,5]	**Weight, kg**	**Weight gain, kg/day**	**Feeding Situation**	**Milk yield, kg/day**[1]	**Fat content of milk, %**	**Protein content of milk, %**	**Work, hrs/day**	**Pregnant, %**	**Digestibility of feed, %**	**CP in diet, %**	**CH_4 Conversion, %**[2]	**Day weighted population mix, %**	**Enteric fermentation EF, CH_4 kg/head/yr**	**kg VS (1000 kg animal mass^{-1}) day^{-1}**	**kg Nex (1000 kg animal mass^{-1}) day^{-1}**	**Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$**
Africa																
Mature Females	356		Pasture/Range	2.4	4.0	3.5	0.55[7]	62	60	11.3	7.0	17	74	9.9	0.41	0.08
Mature Females - grazing	275		Large Areas	1.2	4.1	3.6		54	58	10.0	7.0	11	67	12.1	0.43	0.05
Mature Males	540		Pasture/Range						58	11.2	7.0	2	79	7.3	0.31	0.00
Draft Bullocks[8]	340		Stall Fed				1.1		58	10.0	7.0	4	46	7.8	0.29	0.00
Bulls - Grazing	340		Large Areas						58	10.0	7.0	8	67	9.6	0.36	0.00
Growing/Replacement	204	0.24	Pasture/Range						59	10.4	7.0	42	46	11.0	0.41	0.06
Calves on forage	82	0.33	Pasture/Range						59	10.3	7.0	18	31	18.9	0.65	0.14
Middle East																
Mature Females	372		Pasture/Range	2.4	3.7	3.2		51	61	12.5	7.0	27	71	8.8	0.42	0.07
Mature Males	519		Pasture/Range				0.55		59	12.9	7.0	9	75	7.2	0.35	0.00
Replacement/growing	250	0.33	Pasture/Range						58	12.7	7.0	42	57	11.5	0.52	0.06
Calves on forage	115	0.51	Pasture/Range						58	12.8	7.0	23	46	19.8	0.85	0.12
Indian subcontinent																
Mature Females	253		Pasture/Range	1.7	4.6	3.2		40	55	10.2	7.0	22	62	13.0	0.44	0.07
Mature Males	309		Pasture/Range						57	11.4	7.0	3	53	8.7	0.37	0.00
Draft bullocks[8]	290		Stall Fed				1.7		55	10.0	7.0	43	47	8.6	0.31	0.00
Replacement/growing	152	0.20	Pasture/Range						57	10.9	7.0	16	40	13.4	0.51	0.06
Calves on forage	72	0.26	Pasture/Range						57	11.2	7.0	16	29	20.2	0.75	0.11

TABLE 10A.2 (NEW) (CONTINUED)
DATA FOR ESTIMATING TIER 1 ENTERIC FERMENTATION CH_4 EMISSION FACTORS, VOLATILE SOLID AND NITROGEN EXCRETION RATES, AND N RETENTION FRACTION FOR OTHER CATTLE

[1] The value represent milk yield in kg per day during the whole year.

[2] Y_m values are consist with those reported in Table 10.12.

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

[4] Data of Latin America, Asia, Africa, Middle East and Indian subcontinent were estimated as weighted average by taken into account parameter values related to low production systems and high production systems and livestock population structure of low and high productivity systems. The values were estimated based on the data reported in Table 10A.3.

[5] Scientific articles and reports consulted to derive peformance parameters of dairy and non-dairy cattle are presented in Annex 10B.1.

[6] As Feeding Situation corresponding to high productivity systems is defined as Stall Fed, but for low productivity systems as Pasture/Range, a weigted activitiy coefficient was applied to estimate Net energy for activity.

[7] It was assumed that the whole population of stall fed mature females is not used for draught on the regional scale in Africa.

[8] Draft bullocks were all assumed to be castrates and CF_i values were adjusted accordingly.

TABLE 10A.3 (NEW)
DATA FOR ESTIMATING TIER 1A ENTERIC FERMENTATION CH_4 EMISSION FACTORS, VOLATILE SOLID AND NITROGEN EXCRETION RATES AND N RETENTION FRACTION FOR OTHER CATTLE

Regions[4]	**Weight, kg**	**Weight gain, kg/day**	**Feeding Situation**	**Milk yield, kg/day**[1]	**Fat content of milk, %**	**Protein content of milk, %**	**Work, hrs/day**	**Pregnant, %**	**Digestibility of feed, %**	**CP in diet, %**	**CH_4 Conversion, %**[2]	**Day weighted population mix, %**[3]	**Enteric fermentation EF, CH_4 kg/head/yr**	**kg VS (1000 kg animal mass^{-1}) day^{-1}**	**kg Nex (1000 kg animal mass-^{1}) day^{-1}**	**Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$**
Latin America																
High productivity systems												23[3]				
Mature Females	490		Pasture/Range	2.7	4.2	3.2		78	61	11.2	7.0	33	89	8.4	0.35	0.07
Mature Males	595		Pasture/Range						61	11.2	7.0	1	79	6.2	0.28	0.00
Growing heifers/steers	240	0.50	Pasture/Range						63	11.8	6.3	22	45	9.2	0.40	0.13
Replacement/growing	350	0.50	Pasture/Range						61	11.0	7.0	16	70	9.3	0.38	0.08
Calves on milk	82	0.50	Pasture/Range						95	9.5	0.0	12	0	1.9	0.18	0.49
Calves on forage	200	0.50	Pasture/Range						63	12.3	7.0	12	44	10.8	0.50	0.11
Feedlot cattle	460	0.90	Stall Fed						74	14.0	4.0	4	39	4.8	0.35	0.10
Low productivity systems												77[3]				
Mature Females	420		Pasture/Range	1.8	4.3	3.2		59	59	9.1	7.0	37	79	9.2	0.30	0.07
Mature Males	580		Pasture/Range						59	9.6	7.0	2	81	6.8	0.25	0.00
Growing heifers/steers	240	0.30	Pasture/Range						60	9.2	7.0	22	47	9.3	0.30	0.10
Replacement/growing	290	0.30	Pasture/Range						60	9.3	7.0	19	54	8.9	0.30	0.08
Calves on milk	60	0.30	Pasture/Range						95	9.5	0.0	10	0	1.7	0.16	0.50
Calves on forage	145	0.30	Pasture/Range						60	9.2	7.0	10	35	11.7	0.37	0.14

TABLE 10A.3 (NEW) (CONTINUED)
DATA FOR ESTIMATING TIER 1A ENTERIC FERMENTATION CH$_4$ EMISSION FACTORS, VOLATILE SOLID AND NITROGEN EXCRETION RATES AND N RETENTION FRACTION FOR OTHER CATTLE

Regions[4]	**Weight, kg**	**Weight gain, kg/day**	**Feeding Situation**	**Milk yield, kg/day[1]**	**Fat content of milk, %**	**Protein content of milk, %**	**Work, hrs/day**	**Pregnant, %**	**Digestibility of feed, %**	**CP in diet, %**	**CH$_4$ Conversion, %[2]**	**Day weighted population mix, %[3]**	**Enteric fermentation EF, CH$_4$ kg/head/yr**	**kg VS (1000 kg animal mass^{-1}) day^{-1}**	**kg Nex (1000 kg animal mass^{-1}) day^{-1}**	**Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$**
Asia																
High productivity systems												17[3]				
Mature Females	450		Stall Fed	1.9	4.7	3.3		80	68	12.5	6.3	41	55	5.3	0.30	0.07
Mature Males	550		Stall Fed						68	12.5	6.3	2	49	3.9	0.23	0.00
Growing/Replacement	285	0.40	Stall Fed						68	12.5	6.3	27	41	6.3	0.35	0.07
Calves on forage	125	0.50	Stall Fed						68	12.5	6.3	30	28	9.6	0.47	0.18
Low productivity systems												83[3]				
Mature Females-Farming	350		Stall Fed	1.4	4.7	3.3	1.1	40	59	10.0	7.0	25	64	9.0	0.33	0.06
Mature Females-Grazing	305		Pasture/Range	1.4	4.7	3.3		65	59	10.0	7.0	11	63	10.0	0.36	0.06
Mature Males-Farming	500		Stall Fed				1.1		57	10.0	7.0	18	73	7.4	0.27	0.00
Mature Males-Grazing	430		Pasture/Range						57	10.0	7.0	8	68	8.1	0.30	0.00
Growing/Replacement	190	0.25	Pasture/Range						59	10.0	7.0	25	44	11.3	0.41	0.07
Calves on forage	75	0.30	Pasture/Range						59	10.0	7.0	15	28	18.5	0.61	0.14
Africa																
High productivity systems												30[3]				
Mature Females	390		Pasture/Range	2.9	3.9	3.5		65	61	11.8	7.0	39	76	9.1	0.40	0.09
Mature Males	540		Pasture/Range						58	11.2	7.0	6	79	7.3	0.31	0.00
Growing/Replacement	250	0.34	Pasture/Range						60	11.2	7.0	41	50	9.6	0.39	0.09
Calves on forage	105	0.43	Pasture/Range						61	11.4	7.0	14	36	16.1	0.64	0.14

Table 10A.3 (New) (Continued)
Data for estimating Tier 1A Enteric Fermentation CH_4 Emission Factors, Volatile Solid and nitrogen excretion rates and N retention fraction for Other cattle

Regions[4]	**Weight, kg**	**Weight gain, kg/day**	**Feeding Situation**	**Milk yield, kg/day**[1]	**Fat content of milk, %**	**Protein content of milk, %**	**Work, hrs/day**	**Pregnant, %**	**Digestibility of feed, %**	**CP in diet, %**	**CH_4 Conversion, %**[2]	**Day weighted population mix, %**[3]	**Enteric fermentation EF, CH_4 kg/head/yr**	**kg VS (1000 kg animal mass^{-1}) day^{-1}**	**kg Nex (1000 kg animal mass^{-1}) day^{-1}**	**Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$**
Low productivity systems												70[3]				
Mature Females	275		Pasture/Range	1.2	4.1	3.6	0.55	54	58	10.0	7.0	7	60	11.0	0.39	0.06
Mature Females-Grazing	275		Large Areas	1.2	4.1	3.6		54	58	10.0	7.0	15	67	12.1	0.43	0.05
Draft Bullocks[5]	340		Stall Fed				1.1		58	10.0	7.0	5	53	7.8	0.29	0.00
Bulls - Grazing	340		Large Areas						58	10.0	7.0	11	65	9.6	0.36	0.00
Growing/Replacement	185	0.20	Pasture/Range						58	10.0	7.0	42	42	11.2	0.40	0.06
Calves on forage	75	0.30	Pasture/Range						58	10.0	7.0	20	30	19.9	0.65	0.13
Middle East																
High productivity systems												33[3]				
Mature Females	500		Pasture/Range	2.8	3.5	3.3		55	65	14.0	6.3	20	72	6.8	0.39	0.07
Mature Males	600		Pasture/Range						63	14.0	6.3	12	68	5.6	0.33	0.00
Replacement/growing	350	0.50	Pasture/Range						63	14.0	6.3	42	61	8.6	0.48	0.06
Calves on forage	165	0.70	Pasture/Range						63	14.0	6.3	26	47	14.2	0.74	0.13
Low productivity systems												67[3]				
Mature Females	330		Pasture/Range	2.3	3.8	3.2		50	60	12.0	7.0	30	67	9.7	0.43	0.08
Mature Males	450		Pasture/Range				0.55		55	12.0	7.0	7	79	9.3	0.40	0.00
Replacement/growing	200	0.25	Pasture/Range						55	12.0	7.0	42	50	13.4	0.54	0.05
Calves on forage	85	0.40	Pasture/Range						55	12.0	7.0	21	40	25.3	0.96	0.11

TABLE 10A.3 (NEW) (CONTINUED)
DATA FOR ESTIMATING TIER 1A ENTERIC FERMENTATION CH4 EMISSION FACTORS, VOLATILE SOLID AND NITROGEN EXCRETION RATES AND N RETENTION FRACTION FOR OTHER CATTLE

Regions[4]	Weight, kg	Weight gain, kg/day	Feeding Situation	Milk yield, kg/day[1]	Fat content of milk, %	Protein content of milk, %	Work, hrs/day	Pregnant, %	Digestibility of feed, %	CP in diet, %	CH_4 Conversion, %[2]	Day weighted population mix, %[3]	Enteric fermentation EF, CH_4 kg/head/yr	kg VS (1000 kg animal mass^{-1}) day^{-1}	kg Nex (1000 kg animal mass^{-1}) day^{-1}	Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$
Indian subcontinent																
High productivity systems												14[3]				
Mature Females	300		Pasture/Range	2.5	4.0	3.6		40	60	13.0	7.0	9	64	10.2	0.48	0.09
Mature Males	330		Pasture/Range						60	13.0	7.0	11	52	7.5	0.39	0.00
Replacement/growing	180	0.33	Pasture/Range						60	13.0	7.0	35	45	12.0	0.58	0.07
Calves on forage	90	0.33	Pasture/Range						60	13.0	7.0	45	31	16.7	0.77	0.11
Low productivity systems												86[3]				
Mature Females	250		Pasture/Range	1.7	4.6	3.7		40	55	10.0	7.0	24	62	13.2	0.43	0.08
Mature Males	290		Pasture/Range						55	10.0	7.0	2	54	9.9	0.35	0.00
Draft bullocks[5]	290		Stall Fed				1.7		55	10.0	7.0	50	47	8.6	0.31	0.00
Replacement/growing	140	0.15	Pasture/Range						55	10.0	7.0	13	37	13.9	0.47	0.05
Calves on forage	60	0.22	Pasture/Range						55	10.0	7.0	11	26	23.2	0.73	0.11

[1] The value represent milk yield in kg per day during the whole year.

[2] Ym values are consist with those reported in Table 10.12.

[3] A share of low- and high-productivity animals from the total livestock population of a region.

[4] Scientific articles and reports consulted to derive peformance parameters of dairy and non-dairy cattle are presented in Annex 10B.1.

[5] Draft bullocks were all assumed to be castrates and CF$_i$ values were adjusted accordingly.

TABLE 10A.4 (NEW)
DATA FOR ESTIMATING TIER 1 ENTERIC FERMENTATION CH_4 EMISSION FACTORS, VOLATILE SOLID AND NITROGEN EXCRETION RATES, AND N RETENTION FRACTION RATES FOR BUFFALO

Regions[3]	Weight, kg	Weight gain, kg/day	Feeding Situation	Milk yield, kg/day[1]	Fat content of milk, %	Protein content of milk, %	Work, hrs/day	% Pregnant	Digestibility of feed, %	CP in diet, %	CH_4 Conversion, %[2]	Day weighted population mix, %	Enteric fermentation EF, CH_4 kg/head/yr	kg VS (1000 kg animal mass^{-1}) day^{-1}	kg Nex (1000 kg animal mass^{-1}) day^{-1}	Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$
Western Europe																
Mature Males	700		Stall Fed						65	14.0	6.3	3	59	4.4	0.27	0.00
Mature Females	615		Stall Fed	3.0	8.0	4.6		87	65	15.0	6.3	59	81	6.2	0.36	0.15
Growing/Replacement	420	0.53	Stall Fed						65	14.0	6.3	25	59	6.6	0.39	0.06
Calves	170	0.68	Stall Fed						65	14.0	6.3	13	42	11.7	0.64	0.13
Eastern Europe																
Mature Males	650		Pasture/Paddock						71	13.0	6.3	8	61	3.7	0.26	0.00
Mature Females	550		Pasture/Paddock	4.0	7.5	4.3		85	71	13.0	6.3	62	80	5.8	0.31	0.22
Growing/Replacement	350	0.55	Pasture/Paddock						71	13.0	6.3	14	53	6.0	0.38	0.08
Calves	155	0.66	Pasture/Paddock						71	13.0	6.3	16	37	9.4	0.54	0.16
Latin America																
Adult Males	650		Pasture/Range						60	11.0	7.0	4	86	6.3	0.28	0.00
Adult Females	500		Pasture/Range	4.2	7.1	4.3		62	60	11.0	7.0	40	106	10.1	0.35	0.21
Growing/Replacement	200	0.40	Pasture/Range						60	11.0	7.0	26	47	10.7	0.42	0.09
Calves	90	0.28	Pasture/Range						60	11.0	7.0	30	26	13.9	0.51	0.15
Asia																
Mature Males	490		Pasture/Paddock				1.1		55	10.0	7.0	20	88	9.5	0.34	0.00
Mature Females	420		Pasture/Paddock	1.6	9.1	5.2	1.1	45	55	10.0	7.0	40	99	12.5	0.39	0.12
Growing/Replacement	225	0.26	Pasture/Paddock						55	10.0	7.0	25	56	13.1	0.44	0.05
Calves	90	0.32	Pasture/Paddock						55	10.0	7.0	15	37	22.0	0.69	0.11

TABLE 10A.4 (NEW) (CONTINUED)
DATA FOR ESTIMATING TIER 1 ENTERIC FERMENTATION CH_4 EMISSION FACTORS, VOLATILE SOLID AND NITROGEN EXCRETION RATES, AND N RETENTION FRACTION RATES FOR BUFFALO

Regions[3]	Weight, kg	Weight gain, kg/day	Feeding Situation	Milk yield, kg/day[1]	Fat content of milk, %	Protein content of milk, %	Work, hrs/day	% Pregnant	Digestibility of feed, %	CP in diet, %	CH_4 Conversion, %[2]	Day weighted population mix, %	Enteric fermentation EF, CH_4 kg/head/yr	kg VS (1000 kg animal mass^{-1}) day^{-1}	kg Nex (1000 kg animal mass^{-1}) day^{-1}	Nretention fraction, (kg N retained/animal/day) (kg N intake/animal/day)$^{-1}$
Africa																
Mature Males	590		Pasture/Paddock				1.37		58	10.0	7.0	6	94	8.0	0.30	0.00
Mature Females	440		Pasture/Paddock	4.3	7.2	3.7	0.55	44	58	10.0	7.0	42	107	12.2	0.35	0.24
Growing/Replacement	300	0.40	Pasture/Paddock						58	10.0	7.0	32	68	11.3	0.40	0.07
Calves	115	0.45	Pasture/Paddock						58	10.0	7.0	20	43	18.7	0.61	0.14
Middle East																
Mature Males	650		Pasture/Paddock				1.37		60	11.0	7.0	5	96	7.1	0.31	0.00
Mature Females	520		Pasture/Paddock	3.0	7.0	4.2	0.55	65	65	11.0	6.3	52	83	7.5	0.30	0.17
Growing/Replacement	255	0.39	Pasture/Paddock						61	11.0	7.0	22	54	9.9	0.40	0.08
Calves	105	0.41	Pasture/Paddock						61	11.0	7.0	21	36	16.0	0.61	0.14
Indian subcontinent																
Breeding males	560		Pasture/Paddock						55	12.0	7.0	1	88	8.4	0.36	0.00
Working males[4]	560	8	Pasture/Paddock				1.37		55	12.0	7.0	4	86	8.2	0.35	0.00
Mature Females	480		Pasture/Paddock	4.8	7.3	3.5	0.55	50	55	12.0	7.0	48	127	14.1	0.54	0.09
Growing/Replacement	195	0.31	Pasture/Paddock						59	12.0	7.0	21	45	11.2	0.48	0.08
Calves	85	0.31	Pasture/Paddock						56	12.0	7.0	26	35	21.2	0.83	0.10

[1] The value represent milk yield in kg per day during the whole year.

[2] Ym values are consist with those reported in Table 10.12.

[3] Scientific articles and reports consulted to derive pefromance parameters of buffalo are listed in Annex 10B.1.

[4] Draft bullocks were all assumed to be castrates and CF_i values were adjusted accordingly.

Annex 10A.2 Additional data and information for the calculation of methane and nitrous oxide from Manure Management

This annex presents the required default data to implement the Tier 1 method for estimation of methane and nitrous oxide emissions from manure management. Data required in both methods include animal weight data required for the calculation of average VS and N excretion per animal category as well as AWMS information for regions in the country and improved definitional data, relating IPCC AWMS and definitions used in the EMEP/EEA air pollutant emission inventory guidebook. The information is a combination of the consistent data collection for cattle and buffalo that is compiled in Annex 10A.1 and data compiled by the FAO for use in their modelling system GLEAM (FAO 2017; MacLeod *et al*. 2017). More specific information can be found, sometimes at the country level at http://www.fao.org/gleam/resources/en/. Furthermore, information is supplied on IPCC climate zones.

TABLE 10A.5 (NEW)
DEFAULT VALUES FOR LIVE WEIGHTS FOR ANIMAL CATEGORIES (KG)

Category of animal	Region																		
	North America	Western Europe	Eastern Europe	Oceania	Latin America			Africa			Middle East			Asia			India subcontinent		
					Mean	High PS[1]	Low PS[1]	Mean	High PS	Low PS	Mean	High PS	Low PS	Mean	High PS	Low PS	Mean	High PS	Low PS
Dairy cattle[2]	650	600	550	488	508	520	500	260	250	270	349	510	270	386	485	355	285	350	265
Other cattle[2]	407	405	389	359	303	329	295	236	302	208	275	362	232	299	310	296	226	167	236
Buffalo[2]	NA	509	467	NA	315			339			381			336			321		
Swine[3]	77	76	77	61	65	81	59	49	72	37	59	70	53	58	69	52	59	68	53
Finishing	61	61	59	41	51	59	47	41	54	33	52	60	48	49	56	44	51	55	48
Breeding	184	190	204	163	143	205	121	100	200	61	118	157	99	122	160	102	121	162	99
Chicken[3]	1.4	1.4	1.3	1.3	1.1	1.3	0.9	0.9	1	0.8	0.9	1.2	0.7	1.2	1.4	1	1.0	1.2	0.8
Hens >/= 1 yr	1.5	1.9	1.9	2	1.4	1.6	1.3	1.4	1.9	1.1	1.2	1.7	1	1.5	1.9	1.3	1.3	1.5	1.1
Pullets	1.2	1.5	1.3	1.4	0.7	1.3	0.5	0.7	1.4	0.5	0.6	1.2	0.4	0.8	1.5	0.6	0.6	1.3	0.4
Broilers	1.4	1.2	1.1	1.2	0.9	1.2	0.7	0.8	0.8	0.7	0.7	1	0.5	0.8	1	0.7	0.8	1	0.6
Turkeys[4]	6.8																		
Ducks[4]	2.7																		
Sheep[3]	40				31														
Goats[5]	41	40	36	33	24														
Horses[4]	377				238														
Mules and asses[4]	130																		
Camels[4]	217																		
Ostrich[5]	120																		

TABLE 10A.5 (NEW) (CONTINUED)
DEFAULT VALUES FOR LIVE WEIGHTS FOR ANIMAL CATEGORIES (KG)

<table>
<tr><th rowspan="3">Category of animal</th><th colspan="19">Region</th></tr>
<tr><th rowspan="2">North America</th><th rowspan="2">Western Europe</th><th rowspan="2">Eastern Europe</th><th rowspan="2">Oceania</th><th colspan="3">Latin America</th><th colspan="3">Africa</th><th colspan="3">Middle East</th><th colspan="3">Asia</th><th colspan="3">India sub-continent</th></tr>
<tr><th>Mean</th><th>High PS[1]</th><th>Low PS[1]</th><th>Mean</th><th>High PS</th><th>Mean</th><th>High PS[1]</th><th>Low PS[1]</th><th>Mean</th><th>High PS</th><th>Mean</th><th>High PS[1]</th><th>Low PS[1]</th><th>Mean</th><th>High PS</th></tr>
<tr><td>Deer[5]</td><td colspan="19">120</td></tr>
<tr><td>Reindeer[5]</td><td colspan="19">120</td></tr>
</table>

[1] High PS and Low PS refer to high- and low productivity systems required for Tier 1a methodology.

[2] Values are derived from diets used in the calculation of enteric fermentation Tier 1 and Tier 1a emission factors (Table 10A.1 – Table 10A.4).

[3] Values are taken from FAO GLEAM databases (FAO 2017). High and low estimates are simplified extracts from the model database.

[4] Values are taken from Table 10A-9 of the *2006 IPCC Guidelines*.

[5] For more information see Table 10.10 and Table 10.19 of the *2019 Refinement*.

TABLE 10A.6 (NEW)
ANIMAL WASTE MANAGEMENT SYSTEM (AWMS) REGIONAL AVERAGES FOR CATTLE AND BUFFALO

Animal Category	**Region**[1]	**AWMS (%)**								
		Lagoon	**Liquid /Slurry**	**Solid storage**	**Drylot**	**Pasture/ Range/ Paddock**	**Daily spread**	**Digester**	**Burned for fuel**	**Other**
Dairy Cattle	North America	26	24	24	no data	15	11	no data	no data	no data
	Western Europe	no data	43	29	no data	26	2	no data	no data	no data
	Eastern Europe	no data	5	74	no data	20	1	no data	no data	no data
	Oceania	5	no data	no data	no data	94	1	no data	no data	no data
	East Asia and South-East Asia (Asia)	no data	1	21	29	38	no data	no data	11	no data
	South Asia (Indian subcontinent)	no data	no data	1	49	30	no data	no data	20	no data
	Latin America and the Caribbean	no data	no data	5	38	57	no data	no data	no data	no data
	Near East (Middle East) and North Africa	no data	no data	14	35	46	no data	no data	5	no data
	Sub-Saharan Africat	no data	no data	20	29	45	no data	no data	6	no data
non-Dairy Cattle	North America	no data	1	43	14	42	no data	no data	no data	no data
	Western Europe	no data	22	26	no data	48	4	no data	no data	no data
	Eastern Europe	no data	64	5	no data	31	no data	no data	no data	no data
	Oceania	no data	no data	no data	no data	100	no data	no data	no data	no data
	East Asia and South-East Asia (Asia)	no data	no data	29	28	36	no data	no data	7	no data
	South Asia (Indian subcontinent)	no data	no data	1	49	30	no data	no data	20	no data
	Latin America and the Caribbean	no data	no data	3	5	92	no data	no data	no data	no data
	Near East (Middle East) and North Africa	no data	no data	5	46	42	no data	no data	7	no data
	Sub-Saharan Africa	no data	no data	15	30	50	no data	no data	5	no data

TABLE 10A.6 (NEW) (CONTINUED)
ANIMAL WASTE MANAGEMENT SYSTEM (AWMS) REGIONAL AVERAGES FOR CATTLE AND BUFFALO

Animal Category	Region	AWMS (%)								
		Lagoon	Liquid /Slurry	Solid storage	Drylot	Pasture/ Range/ Paddock	Daily spread	Digester	Burned for fuel	Other
Buffalo Dairy	North America	no data	43	40	no data	17	no data	no data	no data	no data
	Western Europe	no data	34	63	no data	3	no data	no data	no data	no data
	Eastern Europe	no data	18	68	no data	13	1	no data	no data	no data
	East Asia and South-East Asia (Asia)	no data	no data	10	58	29	no data	no data	3	no data
	South Asia (Indian subcontinent)	no data	no data	1	41	38	no data	no data	20	no data
	Latin America and the Caribbean	no data	no data	2	48	50	no data	no data	no data	no data
	Near East (Middle East) and North Africa	no data	no data	18	35	46	no data	no data	1	no data
Buffalo non-Dairy	Eastern Europe (including Russia)	no data	9	64	no data	27	no data	no data	no data	no data
	East Asia and South-East Asia (Asia)	no data	no data	6	64	28	no data	no data	2	no data
	South Asia (Indian subcontinent)	no data	no data	1	40	39	no data	no data	20	no data
	Latin America and the Caribbean	no data	no data	2	5	93	no data	no data	no data	no data
	Near East (Middle East) and North Africa	no data	no data	16	12	57	no data	no data	15	no data

TABLE 10A.7 (NEW)
ANIMAL WASTE MANAGEMENT SYSTEM (AWMS) REGIONAL AVERAGES FOR SWINE (%)

Animal Category	**Productivity class**	**Region**	**Lagoon**	**Liquid/ Slurry**	**Solid storage**	**Drylot**	**Pit < 1**	**Pit > 1**	**Daily spread**	**Digester**	**Pasture**
Growing Swine	High Productivity	North America	28	31	4	3	no data	34	no data	no data	no data
		Western Europe	6	51	14	no data	2	26	1	no data	no data
		Eastern Europe	5	31	55	1	4	4	no data	no data	no data
		Russian Federation	no data	24	76	no data	no data	no data	no data	no data	no data
		Oceania	91	no data	1	8	no data	no data	no data	no data	no data
		East Asia and South East Asia	35	21	no data	2	35	no data	no data	7	no data
		Indian subcontinent	12	23	13	35	2	no data	7	8	no data
		Latin America and the Caribbean	11	34	12	41	no data	no data	2	no data	no data
		Near East (Middle East) and North Africa	10	29	no data	54	no data	no data	no data	7	no data
		Sub-saharan Africa	no data	7	6	86	1	no data	no data	no data	no data
	Low Productivity	East Asia and South East Asia	5	27	18	14	14	5	6	5	6
		Indian subcontinent	5	30	15	15	15	5	5	5	5
		Latin America and the Caribbean	5	30	15	15	15	5	5	5	5
		Near East (Middle East) and North Africa	5	30	15	15	15	5	5	5	5
		Sub-saharan Africa	5	30	15	15	15	5	5	5	5

TABLE 10A.7 (NEW) (CONTINUED)
ANIMAL WASTE MANAGEMENT SYSTEM (AWMS) REGIONAL AVERAGES FOR SWINE (%)

Animal Category	**Productivity class**	**Region**	**Lagoon**	**Liquid/ Slurry**	**Solid storage**	**Drylot**	**Pit < 1**	**Pit > 1**	**Daily spread**	**Digester**	**Pasture**
Breeding Swine	High Productivity	North America	28	31	4	3	no data	34	no data	no data	no data
		Western Europe	6	51	15	no data	2	25	1	no data	no data
		Eastern Europe	5	31	55	1	4	4	no data	no data	no data
		Russian Federation	no data	24	76	no data	no data	no data	no data	no data	no data
		Oceania	91	no data	1	8	no data	no data	no data	no data	no data
		East Asia and South East Asia	35	21	no data	2	35	no data	no data	7	no data
		Indian subcontinent	12	23	14	32	3	no data	8	8	no data
		Latin America and the Caribbean	11	34	12	41	no data	no data	2	no data	no data
		Near East (Middle East) and North Africa	10	29	no data	54	no data	no data	no data	7	no data
		Sub-saharan Africa	no data	7	6	86	1	no data	no data	no data	no data
	Low Productivity	East Asia and South East Asia	4	28	22	13	13	4	6	4	6
		Indian subcontinent	5	30	15	15	15	5	5	5	5
		Latin America and the Caribbean	5	30	15	15	15	5	5	5	5
		Near East (Middle East) and North Africa	5	30	15	15	15	5	5	5	5
		Sub-saharan Africa	5	30	15	15	15	5	5	5	5

TABLE 10A.8 (NEW)
ANIMAL WASTE MANAGEMENT SYSTEM (AWMS) REGIONAL AVERAGES FOR SHEEP AND GOATS

Animal Category	Region[1]	AWMS (%)								
		Lagoon	Liquid/ Slurry	Solid storage	Drylot	Pasture/ Range/ Paddock	Daily spread	Digester	Burned for fuel	Other
Sheep - Meat	North America	no data	no data	54	no data	46	no data	no data	no data	no data
	Western Europe	no data	no data	13	no data	87	no data	no data	no data	no data
	Eastern Europe	no data	no data	54	no data	46	no data	no data	no data	no data
	Near East (Middle East) and North Africa	no data	no data	no data	50	50	no data	no data	no data	no data
	East Asia and South-East Asia	no data	no data	17	3	80	no data	no data	no data	no data
	Oceania	no data	no data	no data	no data	100	no data	no data	no data	no data
	South Asia (Indian subcontinent)	no data	no data	17	3	80	no data	no data	no data	no data
	Latin America and the Caribbean	no data	no data	17	3	80	no data	no data	no data	no data
	Sub-Saharan Africa	no data	no data	17	3	80	no data	no data	no data	no data
Sheep - Dairy	Western Europe	no data	no data	22	no data	78	no data	no data	no data	no data
	Eastern Europe	no data	no data	42	no data	58	no data	no data	no data	no data
	Near East (Middle East) and North Africa	no data	no data	no data	50	50	no data	no data	no data	no data
	East Asia and South-East Asia	no data	no data	17	3	80	no data	no data	no data	no data
	South Asia (Indian subcontinent)	no data	no data	17	3	80	no data	no data	no data	no data
	Latin America and the Caribbean	no data	no data	17	3	80	no data	no data	no data	no data
	Sub-Saharan Africa	no data	no data	17	3	80	no data	no data	no data	no data

TABLE 10A.8 (NEW) (CONTINUED)
ANIMAL WASTE MANAGEMENT SYSTEM (AWMS) REGIONAL AVERAGES FOR SHEEP AND GOATS

Animal Category	Region[1]	AWMS (%)								
		Lagoon	Liquid/ Slurry	Solid storage	Drylot	Pasture/ Range/ Paddock	Daily spread	Digester	Burned for fuel	Other
Goats	North America	no data	no data	50	no data	50	no data	no data	no data	no data
	Russian Federation	no data	no data	82	no data	18	no data	no data	no data	no data
	Western Europe	no data	no data	28	no data	72	no data	no data	no data	no data
	Eastern Europe	no data	no data	9	no data	91	no data	no data	no data	no data
	Near East (Middle East) and North Africa	no data	no data	no data	50	50	no data	no data	no data	no data
	East Asia and South-East Asia	no data	no data	50	no data	50	no data	no data	no data	no data
	Oceania	no data	no data	no data	no data	100	no data	no data	no data	no data
	South Asia (Indian subcontinent)	no data	no data	50	no data	50	no data	no data	no data	no data
	Latin America and the Caribbean	no data	no data	17	3	80	no data	no data	no data	no data
	Sub-Saharan Africa	no data	no data	17	3	80	no data	no data	no data	no data

TABLE 10A.9 (NEW)
ANIMAL WASTE MANAGEMENT SYSTEM (AWMS) REGIONAL AVERAGES FOR POULTRY AND OTHER[1] ANIMALS

Animal Category	**Region**	**AWMS (%)**								
		Lagoon	**Liquid/ Slurry**	**Solid storage**	**Drylot**	**Pasture/ Range/ Paddock**	**Pit >1 month**	**Daily spread**	**Digester**	**Other (Poultry manure with litter)**
Chicken-Layer	North America	1	29	70	no data	no data	no data	no data	no data	no data
	Russian Federation	no data	no data	no data	no data	no data	100	no data	no data	no data
	Western Europe	no data	1	20	21	no data	43	1	no data	14
	Eastern Europe	no data	no data	no data	47	no data	34	no data	no data	19
	Near East (Middle East) and North Africa	11	7	11	no data	no data	67	no data	no data	4
	East Asia and South-East Asia	no data	4	no data	no data	1	94	1	no data	no data
	Oceania	no data	no data	no data	no data	23	77	no data	no data	no data
	South Asia (Indian subcontinent)	no data	no data	100	no data	no data	no data	no data	no data	no data
	Latin America and the Caribbean	no data	58	42	no data	no data	no data	no data	no data	no data
	Sub-Saharan Africa	no data	no data	no data	no data	no data	90	no data	no data	10
Chicken-Broiler	North America	no data	no data	no data	no data	no data	no data	no data	no data	100
	Russian Federation	no data	no data	no data	no data	no data	no data	no data	no data	100
	Western Europe	no data	no data	no data	no data	no data	no data	no data	no data	100
	Eastern Europe	no data	no data	no data	no data	no data	no data	no data	no data	100
	Near East (Middle East) and North Africa	no data	no data	no data	no data	no data	no data	no data	no data	100
	East Asia and South-East Asia	no data	no data	no data	no data	no data	no data	no data	no data	100
	Oceania	no data	no data	no data	no data	no data	no data	no data	no data	100
	South Asia (Indian subcontinent)	no data	no data	no data	no data	no data	no data	no data	no data	100
	Latin America and the Caribbean	no data	no data	no data	no data	no data	no data	no data	no data	100
	Sub-Saharan Africa	no data	no data	no data	no data	no data	no data	no data	no data	100

TABLE 10A.9 (NEW) (CONTINUED)
ANIMAL WASTE MANAGEMENT SYSTEM (AWMS) REGIONAL AVERAGES FOR POULTRY AND OTHER[1] ANIMALS

Animal Category	Region[1]	AWMS (%)								
		Lagoon	Liquid/ Slurry	Solid storage	Drylot	Pasture/ Range/ Paddock	Pit >1 month	Daily spread	Digester	Other (Poultry manure with litter)
Low productivity	North America	no data	no data	no data	no data	50	no data	50	no data	no data
	Russian Federation	no data	no data	no data	no data	50	no data	50	no data	no data
	Western Europe	no data	no data	no data	no data	50	no data	50	no data	no data
	Eastern Europe	no data	no data	no data	no data	50	no data	50	no data	no data
	Near East (Middle East) and North Africa	no data	no data	no data	no data	50	no data	50	no data	no data
	East Asia and South-East Asia	no data	no data	no data	no data	50	no data	50	no data	no data
	Oceania	no data	no data	no data	no data	50	no data	50	no data	no data
	South Asia (Indian subcontinent)	no data	no data	no data	no data	50	no data	50	no data	no data
	Latin America and the Caribbean	no data	no data	no data	no data	50	no data	50	no data	no data
	Sub-Saharan Africa	no data	no data	no data	no data	50	no data	50	no data	no data

[1] For Other animal, the IPCC expert group reviewed the national inventory submissions as well as guidance in the *2006 IPCC Guidelines* under the UNFCCC and concluded that common distribution of systems used to manage manure as follows:

Horses, camelelids, mules and asses, and other grazing animals; should use the data supplied for goats as a proxy;

American bison should use the same manure management fractions as beef cattle in North America;

Deer and reindeer manure deposited at 100% in PRP;

Ostrich (Emu) manure is 80% in PRP and 20 percent managed in solid based systems;

Manure of rabbits and fur-bearing animals is 100% managed in a solid based system.

Hence, countries may apply the same allocation of MMS in the calculation of N_2O emissions from manure stored in manure management systems. However, countries are encouraged to develop a country-specific dataset on MMS used to manage manure generated by these categories of animals.

Information required to determine climate zones according to Chapter 3 of Volume 4 Current Guideline

Outlined below are the conditions required to determine the climate zone required for the selection of a country's MCF, according to the IPCC climate zone determination as defined in Volume 4, Chapter 3, Annex 3A.5, Figure 3A.5.2. Where possible, if countries span multiple climate zones, efforts should be made to disaggregate animal populations into climate zones. If this is not possible, partys are advised to select the climate zone covering the greatest surface area of their country or regions of their country for which they have distinct animal populations.

Briefly, all data is drawn from "The Climate Reseach Unit (CRU) or the CGIAR-Consortium for Spatial Information (CSI) 1985-2015." Climate zones are differentiated based on the factors of mean annual temperature, elevation, mean annual precipitation and the ratio of mean annual precipitation to precipitation for this 30 year average annual weather data compilation.

Therefore, as identified in Volume 4, Chapter 3, of these guidelines climate zones are defined:

Tropical Montane: has > 18^{o}C mean annual temperature and at an elevation greater than 1000m;

Tropical Wet: has > 18^{o}C mean annual temperature and mean annual precipitation >2000mm;

Tropical Moist: has > 18^{o}C mean annual temperature and mean annual precipitation >1000mm;

Tropical Dry: has > 18^{o}C mean annual temperature and mean annual precipitation < 1000mm;

Tropical Moist: has > 18^{o}C mean annual temperature and mean annual precipitation >1000mm;

Warm temperate moist: has > 10^{o}C mean annual temperature and a ratio of potential evapotranspiration to precipitation > 1;

Warm temperate dry: has > 10^{o}C mean annual temperature and a ratio of potential evapotranspiration to precipitation < 1;

Cool temperate moist: has > 0^{o}C mean annual temperature and a ratio of potential evapotranspiration to precipitation > 1;

Cool temperate dry: has > 0^{o}C mean annual temperature and a ratio of potential evapotranspiration to precipitation < 1;

Boreal moist: has < 0^{o}C mean annual temperature but some monthly temperatures > 10^{o}C and a ratio of potential evapotranspiration > 1;

Boreal dry: has < 0^{o}C mean annual temperature but some monthly temperatures > 10^{o}C and a ratio of potential evapotranspiration to precipitation < 1;

Polar moist: has < 0^{o}C mean annual temperature but all monthly temperatures < 10^{o}C and a ratio of potential evapotranspiration > 1;

Polar dry: has < 0^{o}C mean annual temperature but all monthly temperatures < 10^{o}C and a ratio of potential evapotranspiration to precipitation < 1.

Figure 10A.1 (New) **Mapping of IPCC climate zones (taken from Volume 4, Chapter 3, Annex 3A.5)**

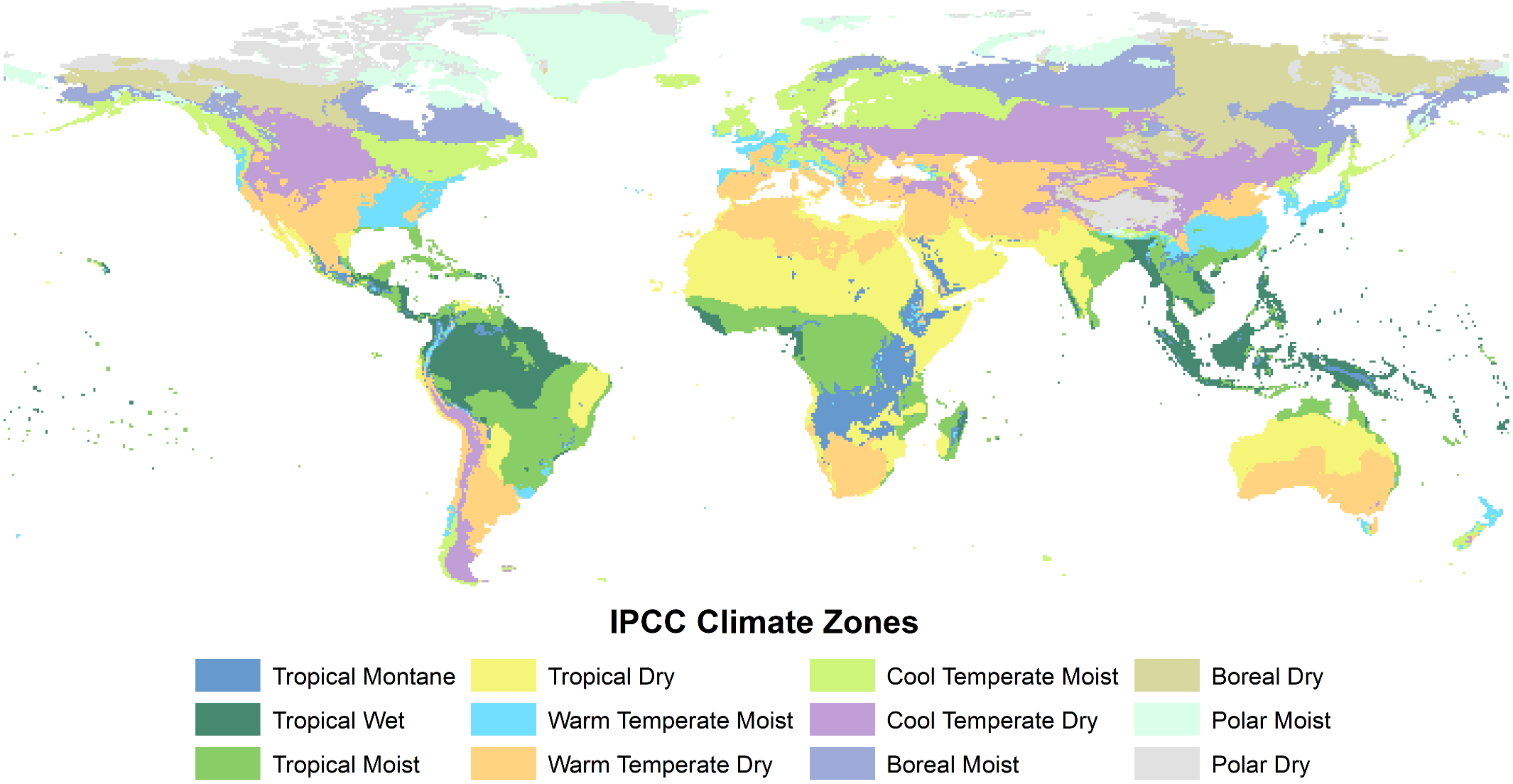


TABLE 10A.10 (NEW)
COMPARISON OF MANURE STORAGE TYPE DEFINITIONS USED BY THE IPCC AND BY THE EMEP/EEA AIR POLLUTANT EMISSION INVENTORY GUIDEBOOK 2016 (HTTPS://WWW.EEA.EUROPA.EU/PUBLICATIONS/EMEP-EEA-GUIDEBOOK-2016)

System IPCC	**System EMEP / EEA**	**Definition**
Pasture/Range/Paddock (PRP)	Grazing	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread	No definition given	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Solid storage	Heaps	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked because of the presence of a sufficient amount of bedding material or loss of moisture by evaporation
Dry lot	No definition given	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	Tanks	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the livestock building, usually for periods of less than 1 year; Storage with a low surface area to depth ratio; normally steel or concrete cylinders
Liquid/Slurry, With natural crust cover	Crust	Natural or artificial layer on the surface of slurry which reduces the diffusion of gasses to the atmosphere
Liquid/Slurry, cover	Cover	Rigid or flexible structure that covers the manure and is impermeable to water and gasses
Uncovered anaerobic lagoon	Lagoons	Storage with a large surface area to depth ratio; normally shallow excavations in the soil
Pit storage below animal confinements	In-house slurry pit	Mixture of excreta and washing water, stored within the livestock building, usually below the confined animals
Anaerobic digester	Biogas treatment	Anaerobic fermentation of slurry and/or solid
Burned for fuel	No definition given	The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel.
Deep bedding	In-house deep litter	Mixture of excreta and bedding, accumulated on the floor of the livestock building

TABLE 10A.10 (NEW) (CONTINUED)
COMPARISON OF MANURE STORAGE TYPE DEFINITIONS USED BY THE IPCC AND BY THE EMEP/EEA AIR POLLUTANT EMISSION INVENTORY GUIDEBOOK 2016 (HTTPS://WWW.EEA.EUROPA.EU/PUBLICATIONS/EMEP-EEA-GUIDEBOOK-2016)

System IPCC		System EMEP / EEA	Definition
Composting	In-vessel	Forced-aeration composting	Aerobic decomposition of manure with forced ventilation
	Static pile	Composting, passive windrow	Aerobic decomposition of manure without forced ventilation
	Intensive windrow	No EMEP equivalent	
	Composting - Passive windrow	No EMEP equivalent	
Poultry manure with litter		Laying hens – solid Broilers – litter Other poultry - litter	Similar to cattle and swine deep bedding except usually not combined with a dry lot or pasture. Typically used for all poultry breeder flocks, 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.
Poultry manure without litter		Laying hens – slurry	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		No EMEP equivalent	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.
No definition given		Slurry separation	The separation of the solid and liquid components of slurry
No definition given		Acidification	The addition of strong acid to reduce manure pH

Annex 10A.3 Spreadsheet example for the calculation of a country or regions specific MCF

MCF CALCULATIONS AND EXAMPLE SPREADSHEET

This Annex was developed to explain how MCFs in the guidelines have been derived and to provide a detailed step by step protocol for inventory compilers to calculate country or region specific MCFs. Application of the model at the national scale requires national or regional monthly air temperature profiles as well as the average number and timing of the emptying of manure storages. Temperature data can be downloaded from various agencies such as the National Oceanic and Atmospheric Administration (NOAA) or the European Environmental Agency. Manure removal statistics may be taken from farm practice surveys or from expert consultation. Compilers should develop an estimate of the average number of manure removals per year and the months of the highest frequency of removals. If regional practices vary within a country, compilers should develop MCFs that are representative of regional practice by entering consistent manure removal statistics with regional temperature profiles. If regional MCFs are calculated, the national MCF should be weighted based on the number of animals feeding into the regional manure management systems represented by the manure removal profile and the regional temperature profile.

Further, to support the *2019 Refinement*, a spreadsheet was created to enable users to calculate a site-specific Methane Conversion Factor (MCF). The spreadsheet uses the same calculations that were used to calculate the MCF Table in the guidance document, but has been designed for use by inventory compilers to do calculations for their country-specific circumstances. The spreadsheed is available in the supplemental data supplied with this Chapter, identified as Supplemental Information Chapter 10, Volume IV, *2019 Refinement*, and available on the IPCC TFI website.

The calculation procedure outlined in the spreadsheet contains three main sections:

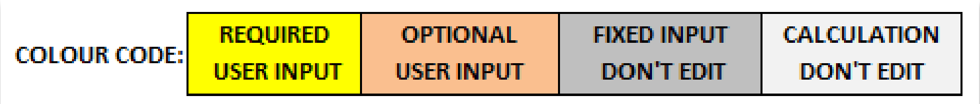
Inputs to the model;

Model calculations;

Results from the model.

As an explanation of procedures, within each section, cells are colour coded. Compilers are required to develop input data for anything that is indicated by yellow highlighted cells, and have the option of editing the orange highlighted cells if needed, but only if country-specific information is available for those parameters. Other cells are not meant to be edited by the user.

Figure 10A.2 (New) Colour code for cells in the example spreadsheet



COLOUR CODE:	REQUIRED USER INPUT	OPTIONAL USER INPUT	FIXED INPUT DON'T EDIT	CALCULATION DON'T EDIT

MODEL INPUT

Temperature

The Input required to run the model at a national scale and recreate the spreadsheet is shown below (Figures 10A.3(New) and 10A.4(New)). In this section, the compiler should input 12 months of temperature data (degrees C) in cells D9:D20, based on average monthly temperatures for the region for which they wish to develop the MCF.

If the compiler has estimates of national or regional manure temperature, "Manure" should be selected in cell D6. As a result, the spreadsheet will copy the user-input temperature into cells E9:E20, for further use in the analysis.

If the compiler is using national or regional air temperature (not manure temperature), "Air" should be selected in cell D6. As a result, the spreadsheet will generate an estimate for manure temperature in cells E9:E20. The estimates are based on the following logic:

- Manure temperature lags 1-month behind air temperature.
  - e.g., Tmanure in June = Tair in May.
- The minimum manure temperature will be used (1 degree C by default; user adjustable).
  - e.g., for Tair = -9 C, Tmanure = 1 C.

If and only if the storage is emptied once per year, manure temperature will be reduced by a dampening factor (3 degrees C by default; user adjustable).

i.e. Tman = Tair – damping factor; e.g., 12 = 15 – 3

The logic equation is implemented in Excel as follows, for example, in cell E9: =IF($D$6="Manure",D9,IF($F$21>1,MAX(D20,f_Tmin),MAX(D20-f_T2damping,f_Tmin)))

Broken into steps:

If $D$6="Manure" then the result in E9 will equal D9

If $D$6 is not "Manure" (i.e. it is "Air") then the second IF statement is operated

IF $F$21>1 (i.e. multiple removals per year), then no damping is applied

Manure temperature is selected as air temperature from the previous month, and it is always greater or equal to the minimum temperature,
i.e. E9 will equal MAX(D20,f_Tmin). In this case, D20 (-6.7) is less than the minimum, so the result in E9 is the minimum (1.0).

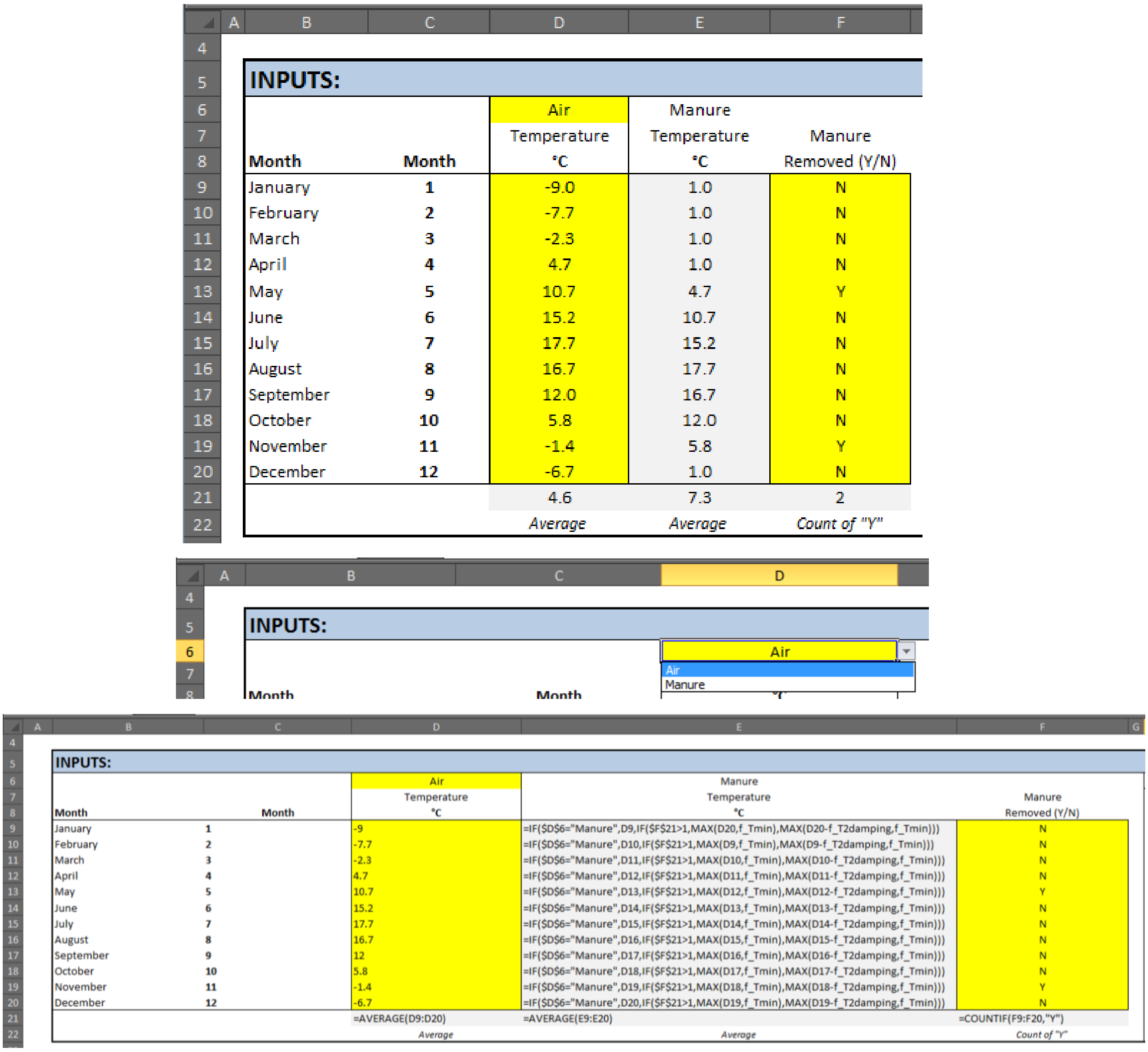
IF $F$21=1 then damping is applied

Damping is applied by subtracting the damping factor: D20-f_T2damping

The temperature is always greater or equal to the minimum temperature, using the MAX() function.

The compiler should then identify the months when manure is removed from the storage in column F (F9:F20). This can be indicated by a "Y" indicating months when manure was removed, and an "N" for months when manure is not removed. The number of months when manure was removed is counted and displayed in cell F21.

Figure 10A.3 (New) **Temperature and manure removal inputs to the model**



INPUTS:

Month	Month	Air Temperature °C	Manure Temperature °C	Manure Removed (Y/N)
January	1	-9.0	1.0	N
February	2	-7.7	1.0	N
March	3	-2.3	1.0	N
April	4	4.7	1.0	N
May	5	10.7	4.7	Y
June	6	15.2	10.7	N
July	7	17.7	15.2	N
August	8	16.7	17.7	N
September	9	12.0	16.7	N
October	10	5.8	12.0	N
November	11	-1.4	5.8	Y
December	12	-6.7	1.0	N
		4.6	7.3	2
		Average	*Average*	*Count of "Y"*

INPUTS:

INPUTS:

Month	Month	Air Temperature °C	Manure Temperature °C	Manure Removed (Y/N)
January	1	-9	=IF($D$6="Manure",D9,IF($F$21>1,MAX(D20,f_Tmin),MAX(D20-f_T2damping,f_Tmin)))	N
February	2	-7.7	=IF($D$6="Manure",D10,IF($F$21>1,MAX(D9,f_Tmin),MAX(D9-f_T2damping,f_Tmin)))	N
March	3	-2.3	=IF($D$6="Manure",D11,IF($F$21>1,MAX(D10,f_Tmin),MAX(D10-f_T2damping,f_Tmin)))	N
April	4	4.7	=IF($D$6="Manure",D12,IF($F$21>1,MAX(D11,f_Tmin),MAX(D11-f_T2damping,f_Tmin)))	N
May	5	10.7	=IF($D$6="Manure",D13,IF($F$21>1,MAX(D12,f_Tmin),MAX(D12-f_T2damping,f_Tmin)))	Y
June	6	15.2	=IF($D$6="Manure",D14,IF($F$21>1,MAX(D13,f_Tmin),MAX(D13-f_T2damping,f_Tmin)))	N
July	7	17.7	=IF($D$6="Manure",D15,IF($F$21>1,MAX(D14,f_Tmin),MAX(D14-f_T2damping,f_Tmin)))	N
August	8	16.7	=IF($D$6="Manure",D16,IF($F$21>1,MAX(D15,f_Tmin),MAX(D15-f_T2damping,f_Tmin)))	N
September	9	12	=IF($D$6="Manure",D17,IF($F$21>1,MAX(D16,f_Tmin),MAX(D16-f_T2damping,f_Tmin)))	N
October	10	5.8	=IF($D$6="Manure",D18,IF($F$21>1,MAX(D17,f_Tmin),MAX(D17-f_T2damping,f_Tmin)))	N
November	11	-1.4	=IF($D$6="Manure",D19,IF($F$21>1,MAX(D18,f_Tmin),MAX(D18-f_T2damping,f_Tmin)))	Y
December	12	-6.7	=IF($D$6="Manure",D20,IF($F$21>1,MAX(D19,f_Tmin),MAX(D19-f_T2damping,f_Tmin)))	N
		=AVERAGE(D9:D20)	=AVERAGE(E9:E20)	=COUNTIF(F9:F20,"Y")
		Average	*Average*	*Count of "Y"*

Note. Top panel: alphanumeric values in each cell. Middle panel: dropdown menu to select "Air" or "Manure". Bottom panel: all formulae are visible.

Constants and Other Input Parameters

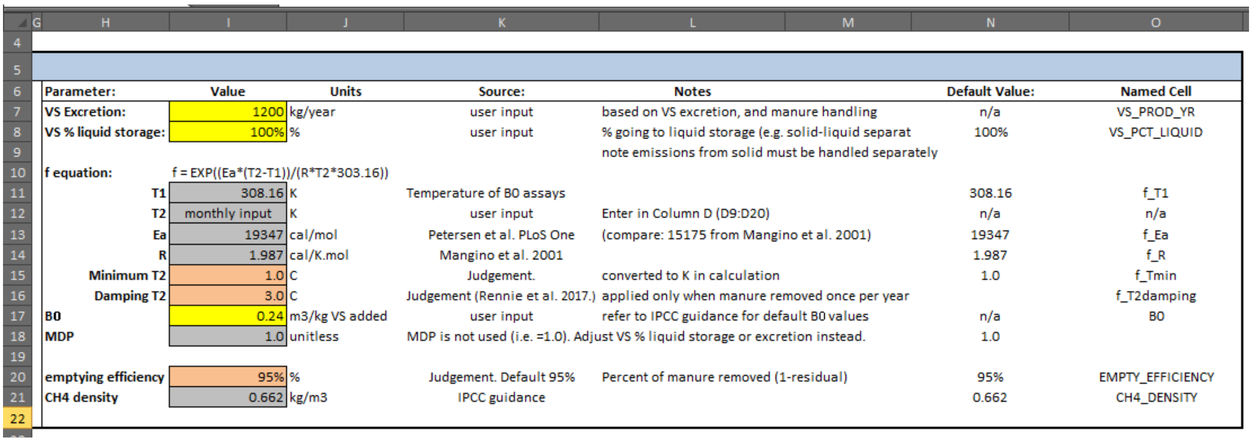
The inventory compiler is required to provide several other inputs in the section shown below (Figure 10A.4(New)). The name of each parameter is provided in column H, the numeric value of the parameter is in column I, the units are in column J, the source of each value is given in column K, additional notes are in columns L and M, default values are in column N. To make equations more easily understood, the Microsoft Excel feature of "Named Cells" has been used to name the cells in column I, and the name of each cell is shown in column O for convenience. For example, cell I7 is given the name "VS_PROD_YR". See Figure 10A.4(New) for a full list of named cells.

Additional information about the input parameters:

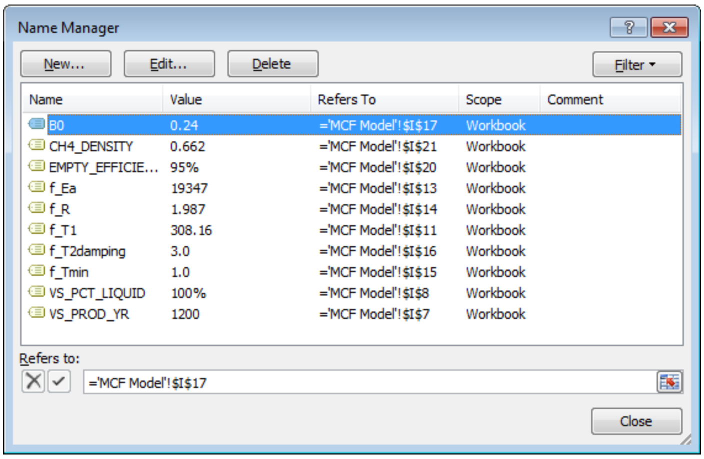
- VS Excretion – based on IPCC guidance.
- VS% liquid storage – this indicates what percentage of excreted VS is handled as a liquid. For example. 100 percent indicates that all excreted VS enters the liquid storage;
- A lower number (say, 75 percent) could indicate that a portion of the solids is separated by a screwpress and handled as a solid (25 percent) while the remaining 75 percent is handled as liquid;
- The compiler must provide a B_0 value for the manure. Refer to IPCC guidance;

- The compiler may, optionally, adjust the minimum temperature (and temperature damping factors);
- The compiler also has the option to adjust the emptying efficiency, which indicates the percentage of manure removed from storage at each removal. By default this is set to 95 percent, indicating that 5 percent of the VS remain in storage after emptying. Set this value to 100 percent for complete removal.

Figure 10A.4 (New) Constants and other input parameters for the model



Parameter:	Value	Units	Source:	Notes	Default Value:	Named Cell
VS Excretion:	1200	kg/year	user input	based on VS excretion, and manure handling	n/a	VS_PROD_YR
VS % liquid storage:	100%	%	user input	% going to liquid storage (e.g. solid-liquid separat	100%	VS_PCT_LIQUID
				note emissions from solid must be handled separately		
f equation:	f = EXP((Ea*(T2-T1))/(R*T2*303.16))					
T1	308.16	K	Temperature of B0 assays		308.16	f_T1
T2	monthly input	K	user input	Enter in Column D (D9:D20)	n/a	n/a
Ea	19347	cal/mol	Petersen et al. PLoS One	(compare: 15175 from Mangino et al. 2001)	19347	f_Ea
R	1.987	cal/K.mol	Mangino et al. 2001		1.987	f_R
Minimum T2	1.0	C	Judgement.	converted to K in calculation	1.0	f_Tmin
Damping T2	3.0	C	Judgement (Rennie et al. 2017.)	applied only when manure removed once per year		f_T2damping
B0	0.24	m3/kg VS added	user input	refer to IPCC guidance for default B0 values	n/a	B0
MDP	1.0	unitless	MDP is not used (i.e. =1.0). Adjust VS % liquid storage or excretion instead.		1.0	
emptying efficiency	95%	%	Judgement. Default 95%	Percent of manure removed (1-residual)	95%	EMPTY_EFFICIENCY
CH4 density	0.662	kg/m3	IPCC guidance		0.662	CH4_DENSITY



Name	Value	Refers To	Scope	Comment
B0	0.24	='MCF Model'!$I$17	Workbook	
CH4_DENSITY	0.662	='MCF Model'!$I$21	Workbook	
EMPTY_EFFICIE...	95%	='MCF Model'!$I$20	Workbook	
f_Ea	19347	='MCF Model'!$I$13	Workbook	
f_R	1.987	='MCF Model'!$I$14	Workbook	
f_T1	308.16	='MCF Model'!$I$11	Workbook	
f_T2damping	3.0	='MCF Model'!$I$16	Workbook	
f_Tmin	1.0	='MCF Model'!$I$15	Workbook	
VS_PCT_LIQUID	100%	='MCF Model'!$I$8	Workbook	
VS_PROD_YR	1200	='MCF Model'!$I$7	Workbook	

Refers to: ='MCF Model'!$I$17

Note. Constants and other input parameters for the model are shown in the top panel. Named Cells in column I are shown in column O, and in the Name Manager dialog box (bottom panel). No formulae exist in this part of the spreadsheet.

MODEL CALCULATIONS

The model calculations are run for three years, in order to ensure VS available has stabilized on an annual basis. For example, in Figure 10A.5(New), we see that VS Available (column J) increases substantially from the first year to the second year (J64 vs J65), and then stabilizes in the third year (J66). This is because the first year begins from a perfectly empty storage, whereas the second year is emptied according to the Emptying Efficiency parameter (95 percent removed / 5 percent remaining; Figure 10A.4(New)).

The model approach is as follows:

Column B: Month of year, over 3 years. These month numbers are used to extract input data shown in Figure 10A.3(New).

Column C: Average manure temperature in each month. This is extracted from cells E9:E20 (Figure 10A.3(New)) using a VLOOKUP function (Figure 10A.6(New)).

Column D: temperature is converted from Celsius to Kelvin, using Excel's CONVERT function 10A.6(New) .

Column E: the temperature-dependent *f* parameter is calculated using the van't Hoff-Arrhenius equation (Mangino *et al*. 2001; IPCC 2006), with updated input parameters shown in Figure 10A.4(New).

Column F: monthly VS excreted is calculated by dividing the annual VS input parameter by 12.

Column G: monthly VS loaded is calculated by multiplying VS excreted by the percentage stored as liquid. In this example, the two are equal because VS_PCT_LIQUID is 100 percent (Figure 10A.4(New)).

Column H: monthly manure emptying is extracted from cells F9:F20 (Figure 10A.3(New)) using a VLOOKUP function (Figure 10A.6(New)).

Column I: the quantity of VS emptied is calculated. The logic is as follows: if emptying occurred, then calculate the mass of VS available to be removed using the mass of VS available in the previous month minus the mass of VS consumed in the previous month. Then, multiply the result by the EMPTY_EFFICIENCY parameter (Figures 10A.4(New) and 10A.6(New)).

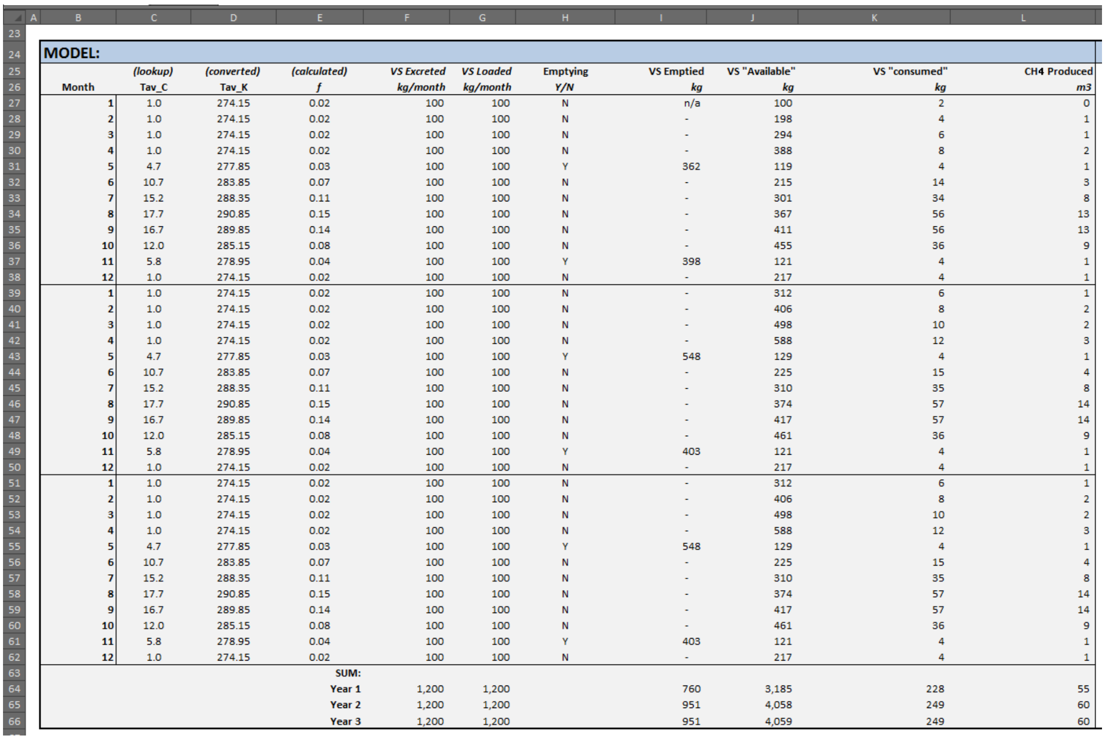
Column J: the mass of VS available for producing methane is calculated. In the first month of the first year this is equal to the mass of VS loaded. In all other months, this is calculated as the VS loaded in the current month + VS available in the previous month – VS consumed in the previous month – VS emptied in the current month.

Column K: the mass of VS consumed is calculated by multiplying VS available by *f*.

Column L: the volume of CH_4 produced is calculated by multiplying VS consumed by B_0.

Using these values and equations, the compiler should be able to reproduce graphics such as the profile of manure temperature, volatile solids and methane production shown in Figure 10A.7(New).

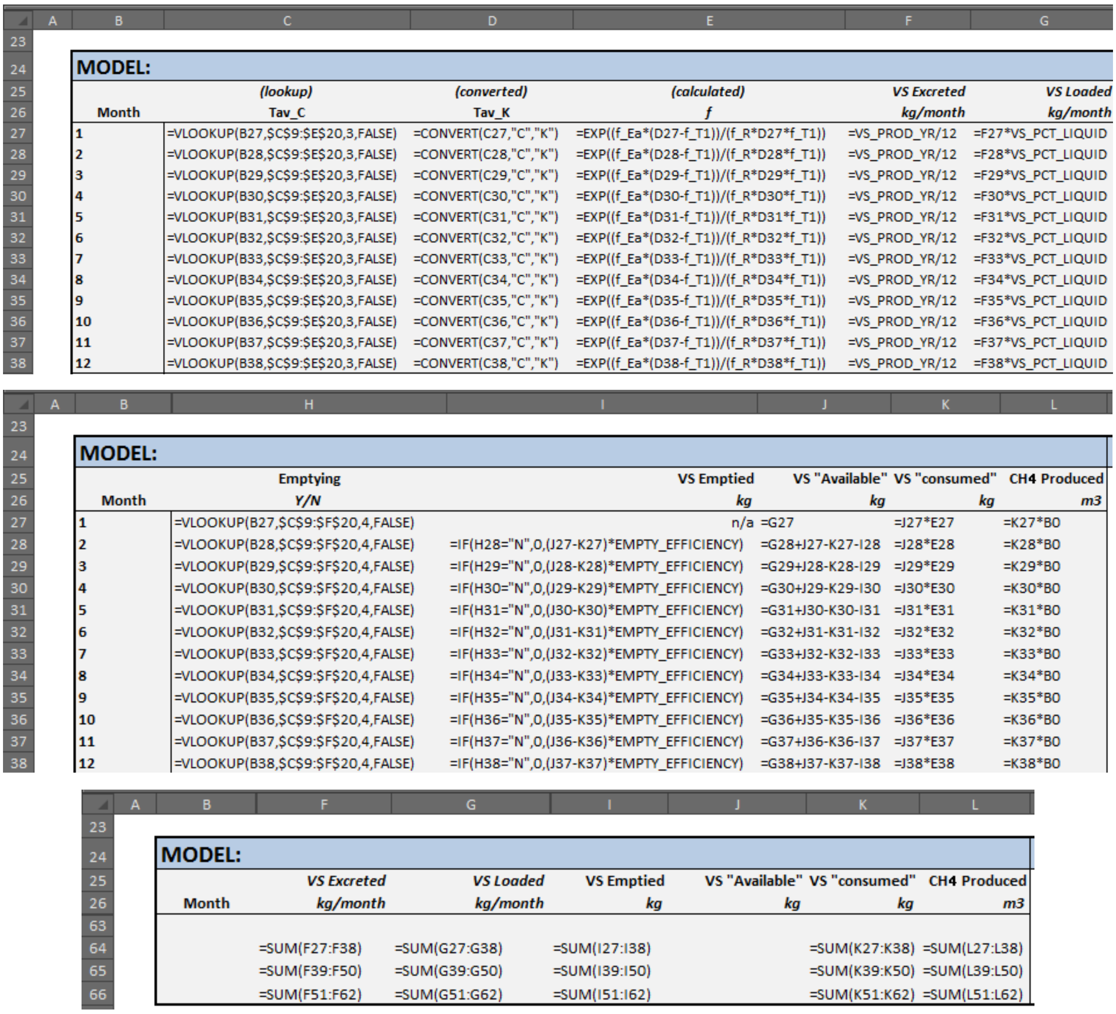
Figure 10A.5 (New) Monthly model inputs and outputs over a three year period



MODEL:

	(lookup)	(converted)	(calculated)	VS Excreted	VS Loaded	Emptying	VS Emptied	VS "Available"	VS "consumed"	CH4 Produced
Month	Tav_C	Tav_K	f	kg/month	kg/month	Y/N	kg	kg	kg	m3
1	1.0	274.15	0.02	100	100	N	n/a	100	2	0
2	1.0	274.15	0.02	100	100	N	-	198	4	1
3	1.0	274.15	0.02	100	100	N	-	294	6	1
4	1.0	274.15	0.02	100	100	N	-	388	8	2
5	4.7	277.85	0.03	100	100	Y	362	119	4	1
6	10.7	283.85	0.07	100	100	N	-	215	14	3
7	15.2	288.35	0.11	100	100	N	-	301	34	8
8	17.7	290.85	0.15	100	100	N	-	367	56	13
9	16.7	289.85	0.14	100	100	N	-	411	56	13
10	12.0	285.15	0.08	100	100	N	-	455	36	9
11	5.8	278.95	0.04	100	100	Y	398	121	4	1
12	1.0	274.15	0.02	100	100	N	-	217	4	1
1	1.0	274.15	0.02	100	100	N	-	312	6	1
2	1.0	274.15	0.02	100	100	N	-	406	8	2
3	1.0	274.15	0.02	100	100	N	-	498	10	2
4	1.0	274.15	0.02	100	100	N	-	588	12	3
5	4.7	277.85	0.03	100	100	Y	548	129	4	1
6	10.7	283.85	0.07	100	100	N	-	225	15	4
7	15.2	288.35	0.11	100	100	N	-	310	35	8
8	17.7	290.85	0.15	100	100	N	-	374	57	14
9	16.7	289.85	0.14	100	100	N	-	417	57	14
10	12.0	285.15	0.08	100	100	N	-	461	36	9
11	5.8	278.95	0.04	100	100	Y	403	121	4	1
12	1.0	274.15	0.02	100	100	N	-	217	4	1
1	1.0	274.15	0.02	100	100	N	-	312	6	1
2	1.0	274.15	0.02	100	100	N	-	406	8	2
3	1.0	274.15	0.02	100	100	N	-	498	10	2
4	1.0	274.15	0.02	100	100	N	-	588	12	3
5	4.7	277.85	0.03	100	100	Y	548	129	4	1
6	10.7	283.85	0.07	100	100	N	-	225	15	4
7	15.2	288.35	0.11	100	100	N	-	310	35	8
8	17.7	290.85	0.15	100	100	N	-	374	57	14
9	16.7	289.85	0.14	100	100	N	-	417	57	14
10	12.0	285.15	0.08	100	100	N	-	461	36	9
11	5.8	278.95	0.04	100	100	Y	403	121	4	1
12	1.0	274.15	0.02	100	100	N	-	217	4	1
			SUM:							
			Year 1	1,200	1,200		760	3,185	228	55
			Year 2	1,200	1,200		951	4,058	249	60
			Year 3	1,200	1,200		951	4,059	249	60

Figure 10A.6 (New) Formulae used in the model



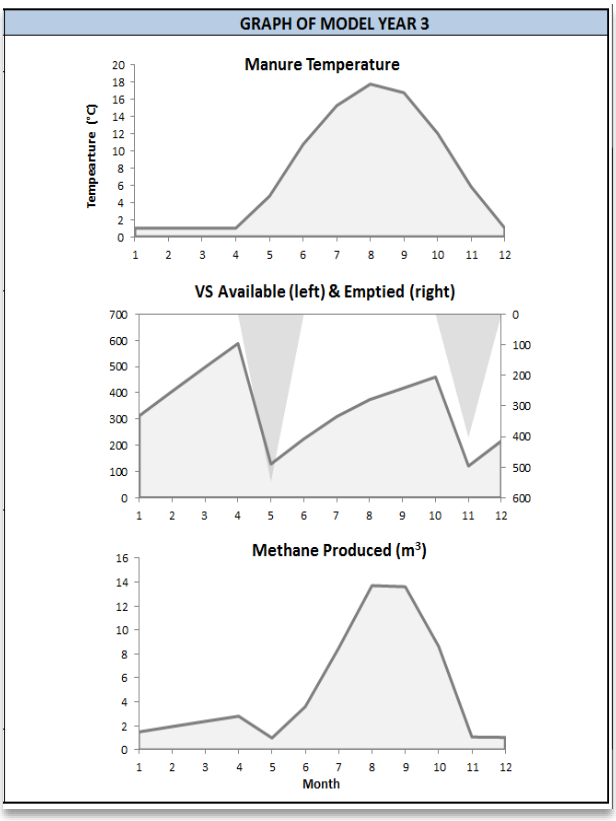
	A	B	C	D	E	F	G
23							
24		**MODEL:**					
25			*(lookup)*	*(converted)*	*(calculated)*	*VS Excreted*	*VS Loaded*
26		**Month**	**Tav_C**	**Tav_K**	***f***	*kg/month*	*kg/month*
27		**1**	=VLOOKUP(B27,$C$9:$E$20,3,FALSE)	=CONVERT(C27,"C","K")	=EXP((f_Ea*(D27-f_T1))/(f_R*D27*f_T1))	=VS_PROD_YR/12	=F27*VS_PCT_LIQUID
28		**2**	=VLOOKUP(B28,$C$9:$E$20,3,FALSE)	=CONVERT(C28,"C","K")	=EXP((f_Ea*(D28-f_T1))/(f_R*D28*f_T1))	=VS_PROD_YR/12	=F28*VS_PCT_LIQUID
29		**3**	=VLOOKUP(B29,$C$9:$E$20,3,FALSE)	=CONVERT(C29,"C","K")	=EXP((f_Ea*(D29-f_T1))/(f_R*D29*f_T1))	=VS_PROD_YR/12	=F29*VS_PCT_LIQUID
30		**4**	=VLOOKUP(B30,$C$9:$E$20,3,FALSE)	=CONVERT(C30,"C","K")	=EXP((f_Ea*(D30-f_T1))/(f_R*D30*f_T1))	=VS_PROD_YR/12	=F30*VS_PCT_LIQUID
31		**5**	=VLOOKUP(B31,$C$9:$E$20,3,FALSE)	=CONVERT(C31,"C","K")	=EXP((f_Ea*(D31-f_T1))/(f_R*D31*f_T1))	=VS_PROD_YR/12	=F31*VS_PCT_LIQUID
32		**6**	=VLOOKUP(B32,$C$9:$E$20,3,FALSE)	=CONVERT(C32,"C","K")	=EXP((f_Ea*(D32-f_T1))/(f_R*D32*f_T1))	=VS_PROD_YR/12	=F32*VS_PCT_LIQUID
33		**7**	=VLOOKUP(B33,$C$9:$E$20,3,FALSE)	=CONVERT(C33,"C","K")	=EXP((f_Ea*(D33-f_T1))/(f_R*D33*f_T1))	=VS_PROD_YR/12	=F33*VS_PCT_LIQUID
34		**8**	=VLOOKUP(B34,$C$9:$E$20,3,FALSE)	=CONVERT(C34,"C","K")	=EXP((f_Ea*(D34-f_T1))/(f_R*D34*f_T1))	=VS_PROD_YR/12	=F34*VS_PCT_LIQUID
35		**9**	=VLOOKUP(B35,$C$9:$E$20,3,FALSE)	=CONVERT(C35,"C","K")	=EXP((f_Ea*(D35-f_T1))/(f_R*D35*f_T1))	=VS_PROD_YR/12	=F35*VS_PCT_LIQUID
36		**10**	=VLOOKUP(B36,$C$9:$E$20,3,FALSE)	=CONVERT(C36,"C","K")	=EXP((f_Ea*(D36-f_T1))/(f_R*D36*f_T1))	=VS_PROD_YR/12	=F36*VS_PCT_LIQUID
37		**11**	=VLOOKUP(B37,$C$9:$E$20,3,FALSE)	=CONVERT(C37,"C","K")	=EXP((f_Ea*(D37-f_T1))/(f_R*D37*f_T1))	=VS_PROD_YR/12	=F37*VS_PCT_LIQUID
38		**12**	=VLOOKUP(B38,$C$9:$E$20,3,FALSE)	=CONVERT(C38,"C","K")	=EXP((f_Ea*(D38-f_T1))/(f_R*D38*f_T1))	=VS_PROD_YR/12	=F38*VS_PCT_LIQUID

	A	B	H	I	J	K	L
23							
24		**MODEL:**					
25			**Emptying**	**VS Emptied**	**VS "Available"**	**VS "consumed"**	**CH4 Produced**
26		**Month**	***Y/N***	***kg***	***kg***	***kg***	***m3***
27		**1**	=VLOOKUP(B27,$C$9:$F$20,4,FALSE)	n/a	=G27	=J27*E27	=K27*B0
28		**2**	=VLOOKUP(B28,$C$9:$F$20,4,FALSE)	=IF(H28="N",0,(J27-K27)*EMPTY_EFFICIENCY)	=G28+J27-K27-I28	=J28*E28	=K28*B0
29		**3**	=VLOOKUP(B29,$C$9:$F$20,4,FALSE)	=IF(H29="N",0,(J28-K28)*EMPTY_EFFICIENCY)	=G29+J28-K28-I29	=J29*E29	=K29*B0
30		**4**	=VLOOKUP(B30,$C$9:$F$20,4,FALSE)	=IF(H30="N",0,(J29-K29)*EMPTY_EFFICIENCY)	=G30+J29-K29-I30	=J30*E30	=K30*B0
31		**5**	=VLOOKUP(B31,$C$9:$F$20,4,FALSE)	=IF(H31="N",0,(J30-K30)*EMPTY_EFFICIENCY)	=G31+J30-K30-I31	=J31*E31	=K31*B0
32		**6**	=VLOOKUP(B32,$C$9:$F$20,4,FALSE)	=IF(H32="N",0,(J31-K31)*EMPTY_EFFICIENCY)	=G32+J31-K31-I32	=J32*E32	=K32*B0
33		**7**	=VLOOKUP(B33,$C$9:$F$20,4,FALSE)	=IF(H33="N",0,(J32-K32)*EMPTY_EFFICIENCY)	=G33+J32-K32-I33	=J33*E33	=K33*B0
34		**8**	=VLOOKUP(B34,$C$9:$F$20,4,FALSE)	=IF(H34="N",0,(J33-K33)*EMPTY_EFFICIENCY)	=G34+J33-K33-I34	=J34*E34	=K34*B0
35		**9**	=VLOOKUP(B35,$C$9:$F$20,4,FALSE)	=IF(H35="N",0,(J34-K34)*EMPTY_EFFICIENCY)	=G35+J34-K34-I35	=J35*E35	=K35*B0
36		**10**	=VLOOKUP(B36,$C$9:$F$20,4,FALSE)	=IF(H36="N",0,(J35-K35)*EMPTY_EFFICIENCY)	=G36+J35-K35-I36	=J36*E36	=K36*B0
37		**11**	=VLOOKUP(B37,$C$9:$F$20,4,FALSE)	=IF(H37="N",0,(J36-K36)*EMPTY_EFFICIENCY)	=G37+J36-K36-I37	=J37*E37	=K37*B0
38		**12**	=VLOOKUP(B38,$C$9:$F$20,4,FALSE)	=IF(H38="N",0,(J37-K37)*EMPTY_EFFICIENCY)	=G38+J37-K37-I38	=J38*E38	=K38*B0

	A	B	F	G	I	J	K	L
23								
24		**MODEL:**						
25			***VS Excreted***	***VS Loaded***	**VS Emptied**	**VS "Available"**	**VS "consumed"**	**CH4 Produced**
26		**Month**	***kg/month***	***kg/month***	***kg***	***kg***	***kg***	***m3***
63								
64			=SUM(F27:F38)	=SUM(G27:G38)	=SUM(I27:I38)		=SUM(K27:K38)	=SUM(L27:L38)
65			=SUM(F39:F50)	=SUM(G39:G50)	=SUM(I39:I50)		=SUM(K39:K50)	=SUM(L39:L50)
66			=SUM(F51:F62)	=SUM(G51:G62)	=SUM(I51:I62)		=SUM(K51:K62)	=SUM(L51:L62)

Note. To conserve space, only 12 months are shown. Top panel: Temperature (Column C and D), coefficient (Column E), VS excreted, (Column F) and VS loaded (Column G). Middle panel: month of emptying (Columns H), VS emptied (Column I), VS available (Column J), VS consumed (Column K) and CH_4 Produced (Column L). Bottom panel: sums in rows 64:66 for selected columns.

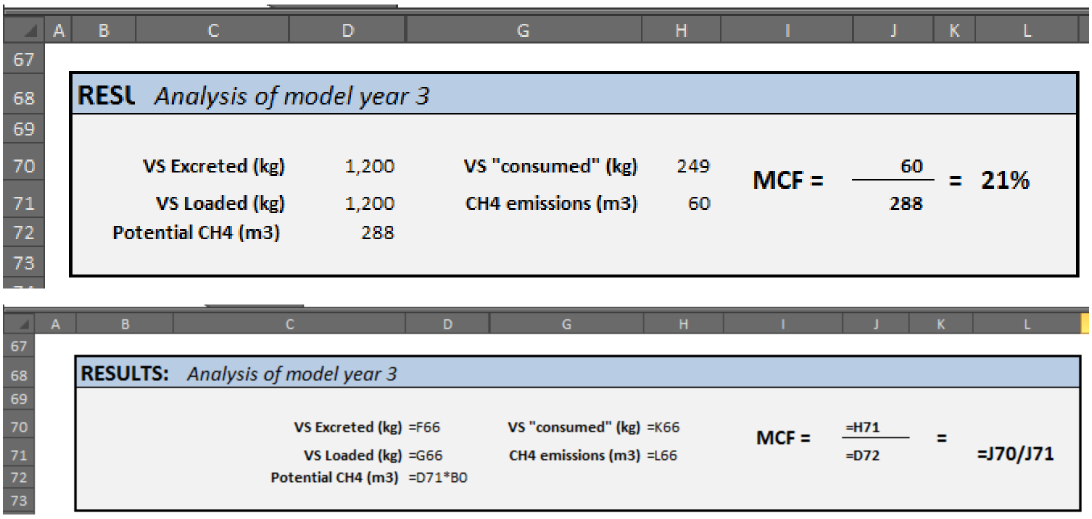
Figure 10A.7 (New) **Example of monthly patterns in Year 3: manure temperature, VS available (kg), VS emptied (kg), and methane production.**



MODEL RESULTS

The MCF is calculated in the Results section. This is done using the third year outputs. In this particular example, the input air temperature is from the Cool Temperate Moist region and the retention time is 6-months. The resulting MCF (21 percent) is identical with the guidance document (21 percent).

Figure 10A.8 (New) **Summary of Year 3 VS and methane production, and calculation of MCF.**



RESL *Analysis of model year 3*

VS Excreted (kg) 1,200
VS Loaded (kg) 1,200
Potential CH4 (m3) 288
VS "consumed" (kg) 249
CH4 emissions (m3) 60

$$\text{MCF} = \frac{60}{288} = 21\%$$

RESULTS: *Analysis of model year 3*

VS Excreted (kg) =F66
VS Loaded (kg) =G66
Potential CH4 (m3) =D71*B0
VS "consumed" (kg) =K66
CH4 emissions (m3) =L66

$$\text{MCF} = \frac{\text{=H71}}{\text{=D72}} = \text{=J70/J71}$$

Note. Top panel shows results, bottom panel shows equations.

NOTE ABOUT TERMINOLOGY:

The terms "VS Available" and "VS Consumed" are used here to be consistent with the *2006 IPCC Guidelines* and Mangino *et al*. 2001 approach. However, these terms require some clarification to avoid misinterpretation: (1)

The term “VS Consumed” does not represent the real VS degraded but a conceptual quantity of VS removed from the liquid/slurry storage against the total biomethane potential at 35°C (i.e. the conceptual proportion of the B_0 consumed at that point). Therefore, just as B_0 reports the quantity of CH_4 produced per kg of VS (i.e. all fractions, degradable and non-degradable), the concept of “VS Consumed” removes all fractions of VS from storage. This approach is convenient because it uses the B_0 as the integrator of all fractions of VS degradability, and reports the total methane produced from all fractions as if they were incubated for infinite time, while the *f* parameter introduces a temperature dependence. Though this is convenient for modelling, and is consistent with the B_0, this does not represent the physical reality of the liquid/slurry storage. (2) Since “VS Consumed” does not equate with the amount of VS degraded in the storage, the “VS available” does equate with the amount of VS that would actually be measured in a storage. Therefore, researchers should not attempt to compare measured VS with “VS available”. (3) The strength of this approach is its simplicity and the fact that the maximum amount of methane that can be produced is equal to the total VS produced multiplied by the B_0. In other words, the model cannot produce more methane than the B_0. (4) The MCF is the ratio of predicted “VS Consumed” to the total VS that entered the storage over one year. The method does not address VS destruction. If the “VS Consumed” were multiplied by B’ (m^3 CH_4/kg VS destroyed), the result be would be erroneous because “VS Consumed” is not VS Destroyed. This is not to say that B’ cannot be used to model methane production, but simply that it is not compatible with the “VS Consumed” concept. (5) Although B_0 does not need to enter the MCF calculation, the role of B_0 is to be multiplied by the MCF, as stated in equation 10.23 of the *IPCC 2006 Guidelines* and this *2019 Refinement*.

Annex 10A.4 Calculations of Methane Conversion Factors (MCFs) for biogas systems

MCFs for the biogas digester

Biogas digesters are an important manure management systems. There are different types of biogas digesters, including centralised biogas digester plants, animal farm based biogas digesters, and digesters that co-digest animal manures and organic residues. Some biogas digesters such as farm based biogas digesters may include prestorage, like pit storage below animal confinement, or outdoor storage. Co-digestion may include energy crops, and/or different types of organic waste in varying combinations.

Default MCFs of biogas digesters are provided in Table 10.17 and Table 10A.11.

MCFs depend on the amount of B_0 that is realised under on farm conditions and on the amount of produced biogas that leakes from the biogas plant either during storage or energy production. Calculations to identify default factors were carried out by varying the level of leakage from the biogas installations. Calculations are based on a modification of the default values in Table 10.17 and Table 10A.11using the equation defined in Haenel *et al.* (2018).

TABLE 10A.11 (NEW)
METHANE CONVERSION FACTOR (MCF_{DG}) INCLUDING BIOGAS DIGESTER AND DIGESTATE STORAGE[1]

Biogas digester quality	Storage gastight level	Climate Zone		
		cold	temperate	warm
high quality biogas digester, Ldig=0.01	High quality gastight storage, $L_{sto,gt}$ =0.01	1.00%	1.00%	1.00%
	Low quality gastight storage, $L_{sto,gt}$ =0.1	1.41%	1.41%	1.41%
	Open storage, $L_{sto,gt}$=1	3.55%	4.38%	4.59%
	Average	1.99%	2.27%	2.33%
low quality biogas digester, Ldig=0.1	High quality gastight storage, $L_{sto,gt}$=0.01	9.59%	9.59%	9.59%
	Low quality gastight storage, $L_{sto,gt}$ =0.1	10.00%	10.00%	10.00%
	Open storage, $L_{sto,gt}$ =1	12.14%	12.97%	13.17%
	Average	10.58%	10.85%	10.92%

[1] the value of MCF for digestate storage (MCF_{ngts}) is based on the MCF value of anaerobic lagoon.

Methane emissions from biogas digesters include the unused biogas (can be defined as leakage) and emissions from storage of the digestate. The MCF calculation from biogas digesters should be based on the following equation (Haenel *et al.* 2018):

EQUATION 10A.1 (NEW)
CALCULATION OF MCF FOR THE COMBINATION "DIGESTER + DIGESTATE STORAGE"

$$MCF_{dg} = \frac{v_{CH_4,prod} - v_{CH_4,used} - v_{CH_4,\ flared} + MCF_{residues} \bullet \left(B_0 - v_{CH_4,prod}\right)}{B_0}$$

Where:

MCF_{dg} = effective methane conversion factor for the combination "digester + digestate storage", percent

$v_{CH_4,prod}$ = specific volume of methane produced in the digester (related to VS input), m^3 CH_4 kg^{-1} VS

$v_{CH_4,used}$ = specific volume of methane used for energy production (related to VS input), m^3 CH_4 kg^{-1} VS

$v_{CH_4,\ flared}$ = specific volume of methane flared (related to VS input), m^3 CH_4 kg^{-1}VS

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

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

In practice, the residence time necessary to fully exploit the maximum methane producing capacity B_0 is not fully reached in the gas collection system. In the following, the difference, i.e. the potentially still purgeable amount of gas ($B_0 - v_{CH_4,prod}$), is denoted as "potential of residual gas" that is assumed to be known, and the ratio of which to B_0 is described by the entity μ_{rg}:

EQUATION 10A.2 (NEW)
CALCULATION OF RELATIVE AMOUNT OF POTENTIAL OFF GAS RELATED TO B_0

$$\mu_{rg} = \frac{B_0 - v_{CH_4,prod}}{B_0}$$

Where:

μ_{rg} = relative amount of residual gas related to B_0 (with $0 \leq \mu_{rg} \leq 1$ m^3 m^{-3})

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

$v_{CH_4,prod}$ = specific volume of methane produced in the digester (related to VS input), m^3 CH_4 kg^{-1} VS

In practice, the amount of residual gas, μ_{rg} 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_{rg} can be defined which is closely related to μ_{rg} .

The μ_{rg} can be calculated as follows:

EQUATION 10A.3 (NEW)
CALCULATION OF RELATIVE AMOUNT OF RESIDUAL GAS RELATED TO B_0

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

Where:

μ_{rg} = relative amount of residual gas related to B_0 (with $0 \leq \mu_{rg} \leq 1$ m^3 m^{-3})

v_{rg} = relative amount of residual gas related to $v_{CH4,prod}$ (with $0 \leq v_{rg} \leq 1$ m^3 m^{-3})

EQUATION 10A.4 (NEW)
CALCULATION OF RELATIVE AMOUNT OF RESIDUAL GAS RELATED TO CH_4 PRODUCTION

$$v_{rg} = \frac{B_0 - v_{CH_4,prod}}{v_{CH_4,prod}}$$

Where:

v_{rg} = relative amount of residual gas related to $v_{CH4,prod}$ (with $0 \leq v_{rg} \leq 1$ m^3 m^{-3})

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

$v_{CH_4,prod}$ = specific volume of methane produced in the digester (related to VS input), m^3 CH_4 kg^{-1}VS

The term $v_{CH_4,prod} - v_{CH_4,used} - v_{CH_4,\ flared}$ in equation 10A.1 is part of the digester's methane balance (related to VS input) which can be completed by the methane loss $v_{CH_4,leak}$ due to leakage.

EQUATION 10A.5 (NEW)
DIGESTER'S METHANE BALANCE

$$v_{CH_4,prod} - v_{CH_4,used} - v_{CH_4,\ flared} - v_{CH_4,leak} = 0$$

Where:

$v_{CH_4,prod}$ = specific volume of methane produced in the digester (related to VS input), m^3 CH_4 kg^{-1} VS

$v_{CH_4,used}$ = specific volume of methane used for energy production (related to VS input), m^3 CH_4 kg^{-1} VS

$v_{CH_4,\ flared}$ = specific volume of methane flared (related to VS input), m^3 CH_4 kg^{-1}VS

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

The loss of methane $v_{CH_4,leak}$ due to leakage is calculated as part of the total amount of CH_4 produced in the digester. The ratio of these two quantities is defined as the leakage rate L_{dig} of the digester. L_{dig} is assumed to be known.

EQUATION 10A.6 (NEW)
CALCULATION OF METHANE LEAKAGE RATE OF DIGESTER

$$v_{CH4,leak} = L_{dig} \bullet v_{CH4,prod}$$

Where:

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

L_{dig} = leakage rate of the digester, related to $v_{CH_4,prod}$(with $0 \leq L_{\text{dig}} \leq 1$ m^3 m^{-3}).

$v_{CH_4,prod}$ = specific volume of methane produced in the digester (related to VS input), m^3 CH_4 kg^{-1} VS

In order to give the effective methane conversion factor of the combination, "digester + digestate storage" as a function of the three parameters, "relative amount of residual gas", "leakage rate" and "MCF of the digestate storage", the methane conversion factor of the combination, "digester + digestate storage" can be calculated as follows (Equation 10A.7):

EQUATION 10A.7 (NEW)
CALCULATION OF METHANE CONVERSION FACTOR

$$MCF_{dg} = \left(1 - \mu_{rg}\right) \bullet L_{dig} + \mu_{rg} \bullet MCF_{residues}$$

Where:

MCF_{dg} = effective methane conversion factor for the combination "digester + digestate storage", percent

μ_{rg} = relative amount of residual gas related to B_0 (with $0 \leq \mu_{rg} \leq 1$ m^3 m^{-3})

L_{dig} = leakage rate of the digester, related to $v_{CH4,prod}$ (with $0 \leq L_{dig} \leq 1$ m^3 m^{-3})

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

For the factors of L_{dig} and μ_{rg} it is recommended to use country-specific data; if country specific data are unavailable. the following procedure is recommended: For high quality biogas digesters, the default L_{dig} is recommended to be 0.01 (Rösemann *et al.* 2017); for low quality biogas digesters, L_{dig} = 0.1 is recommended (Table 10A-4 to Table 10A-9 *2006 IPCC Guidelines*). The value of 0.046 is used for µrg based on Haenel *et al.* (2018) The values presented in Table 10A.11 are derived using Equation 10A.7 and the values cited here. Pre-storage loss estimates are not included as no default values can be identified from the literature. Also, it is assumed that these losses will be low as they represent economic losses due to lower biogas production. However equations are included below if compilers wish to adapt their emission estimates to country-specific circumstances.

It is assumed that even a gastight storage of digestate has a certain leakage. This leakage rate is described by the storage-specific leakage rate $L_{sto,gt}$. Taking into account the leakage rate and the relative share of gastight storage of digestate x_{gts}, the $MCF_{residues}$ can be calculated following Equation 10A.8:

EQUATION 10A.8 (NEW)
CALCULATION OF METHANE CONVERSION FACTOR OF RESIDUES

$$MCF_{residues} = x_{gts} \bullet L_{sto,gt} + \left(1 - \frac{x_{gts}}{100}\right) \bullet MCF_{ngts}$$

Where:

$MCF_{residues}$ = methane conversion factor for the storage of digestate, percent

x_{gts} = share of gastight storage of the digestate, percent

$L_{sto,gt}$ = leakage rate of the gastight storage (with $0 \le L_{sto,gt} \le 1$ m^3 m^{-3}). For high quality gastight storage of the digestate $L_{sto,gt}$ is assumed to be 0.01 m^3 m^{-3}. For low quality gastight storage of the digestate, $L_{sto,gt}$ is assumed to be 0.1 m^3 m^{-3}. For open storage of the digestate, $L_{sto,gt}$ is assumed to be 1.0 m^3 m^{-3}

MCF_{ngts} = methane conversion factor for the non-gastight storage of digestate, percent. It is assumed that MCF_{ngts} is same to the storage of raw manure.

Biogas plants that are fed with animal manures have, as a rule, a pre-storage for the feedstock before it enters the digester. The CH_4 losses from the pre-storage reduce the CH_4 production potential in the digester and the storage of the digestate. This could be taken into account by modifying equations 10A.7. As a consequence Equation (10A.7) is transformed to the $MCF_{\mathrm{dg+ps}}$ equation as Equation 10A.9.

EQUATION 10A.9 (NEW)
CALCULATION OF METHANE CONVERSION FACTOR FOR THE COMBINATION "PRESTORAGE + DIGESTER + DIGESTATE STORAGE"

$$\begin{aligned} MCF_{\mathrm{dg+ps}} &= MCF_{ps} + \left(1 - MCF_{ps}\right) \bullet MCF_{dg} \\ &= MCF_{ps} + (1 - MCF_{ps}) \bullet [(1 - \mu_{\mathrm{rg}}) \bullet L_{\mathrm{dig}} + \mu_{\mathrm{rg}} \bullet MCF_{residues}] \end{aligned}$$

Where:

$MCF_{\mathrm{dg+ps}}$ = effective methane conversion factor for the combination "prestorage + digester +digestate storage", percent

MCF_{ps} = methane conversion factor for prestorage, percent; Table 10.17 provides the default values for different prestorage systems

MCF_{dg} = methane conversion factor for combination "digester+digestate storage", percent, see above

μ_{rg} = relative amount of residual gas related to B_0 (with $0 \leq \mu_{rg} \leq 1$ m^3 m^{-3})

L_{dig} = leakage rate of the digester, related to $\nu_{CH4,prod}$ (with $0 \leq L_{dig} \leq 1$ m^3 m^{-3})

$MCF_{residues}$ = methane conversion factor for the storage of digestate (in m^3 m^{-3}).

Annex 10A.5 Equations relating all direct and indirect N_2O emissions from manure along all stages in agricultural production for livestock

As explained in section 10.5.6, nitrogen excreted by animals contributes to several direct and indirect N_2O emission as it cascades through livestock and crop cultivation systems. It is therefore crucial to accurately estimate nitrogen excretion rates. The total direct and indirect N_2O emissions associated with the excretion of nitrogen of an animal type is an important quantity to assess the benefit from improving the estimation of the N-excretion coefficient for that animal type. However, the total direct and indirect N_2O emissions from animal excretion cannot be easily estimated using the equations given in Chapter 10 and 11 of the *2006 IPCC Guidelines* and this *2019 Refinement*. This annex provides a set of equations, based on the equations given in Chapter 10 and 11, that allows the quantification of total direct and indirect N_2O emissions from nitrogen excretion of each animal type *T*. They are reported in Equations 10A.10 through 10A27.

The definition of the symbols used in the set of equations is given below Equation 10A.27, grouped by symbols. Note that for internal consistency, the symbol *N* is used for all nitrogen flows in kg N animal^{-1} yr^{-1}; the symbol *F* is used for all animal-independent nitrogen flows or nitrogen flows for the total animal population in kg N yr^{-1}; the symbol *Frac* is used for all fractions in kg N (kg N)$^{-1}$ or percent, the symbol *EF* is used for all N_2O emission factors in kg N_2O-N (kg N)$^{-1}$, and the symbol N_2O is used for all N_2O emissions in kg N_2O-N yr^{-1} . Not in all cases therefore, the symbols are identical to those used in the Equations given in Chapters 10 and 11.

EQUATION 10A.10 (NEW)
TOTAL N_2O EMISSIONS FOR ANIMAL TYPE *T*

$$N_2O_{(T)} = N_2O_{mm(T)} + N_2O_{AM(T)} + N_2O_{PRP(T)}$$

EQUATIONS 10A.11 AND 10A.12 (NEW)
TOTAL N_2O EMISSIONS FROM MANURE MANAGEMENT FOR ANIMAL TYPE *T*

$$N_2O_{(mm,T)} = N_2O_{D(mm,T)} + N_2O_{G(mm,T)} + N_2O_{L(mm,T)}$$

$$N_2O_{mm(T)} = \left(\sum_S F_{mm(T,S)} \bullet \left[EF_{3(S)} + \left(Frac_{GasMS} \right)_{(T,S)} \bullet EF_4 + \left(Frac_{LeachMS} \right)_{(T,S)} \bullet EF_5 \right] \right) \bullet \frac{44}{28}$$

EQUATIONS 10A.13 THROUGH 10A.14 (NEW)
TOTAL, DIRECT AND INDIRECT N_2O EMISSIONS FROM THE APPLICATION OF MANURE TO MANAGED SOILS FOR ANIMAL TYPE *T*

$$N_2O_{AM(T)} = N_2O_{D,AM(T)} + N_2O_{I,AM(T)}$$

$$N_2O_{D,AM(T)} = F_{AM(T)} \bullet \left[\left(1 - Frac_{AM,Rice} \right) \bullet EF_1 + Frac_{AM,Rice} \bullet EF_{1FR} \right] \bullet \frac{44}{28}$$

$$N_2O_{I,AM(T)} = F_{AM(T)} \bullet \left[Frac_{GASM} \bullet EF_4 + Frac_{LEACH-(H)} \bullet EF_5 \right] \bullet \frac{44}{28}$$

EQUATION 10A.15 (NEW)
TOTAL AMOUNT OF ANIMAL MANURE N APPLIED TO SOILS OTHER THAN BY GRAZING ANIMALS FOR ANIMAL TYPE *T*

$$F_{AM(T)} = \left\{ \sum_{S} \left[\left(F_{mm(T,S)} \bullet \left(1 - Frac_{LossMS}\right)_{(T,S)} \right) + F_{bedding(T,S)} \right] + F_{codigestate} \right\} \bullet Frac_{APPL(T)}$$

EQUATION 10A.16 (NEW)
FRACTION OF TOTAL ANIMAL MANURE N LOST IN MANURE MANAGEMENT SYSTEMS FOR ANIMAL TYPE *T*

$$Frac_{LossMS(T,S)} = Frac_{GASMS(T,S)} + Frac_{LEACHMS(T,S)} + Frac_{N_2MS(S)} + EF_{3(S)}$$

EQUATION 10A.17 (NEW)
FRACTION OF ANIMAL MANURE N AVAILABLE FOR APPLICATION TO MANAGED SOILS, APPLIED TO MANAGED SOILS FOR ANIMAL TYPE *T*

$$Frac_{APPL(T)} = 1 - \left(Frac_{FEED(T)} + Frac_{FUEL(T)} + Frac_{CNST(T)} \right)$$

EQUATION 10A.18 THROUGH 10A.19 (NEW)
TOTAL, DIRECT AND INDIRECT N2O EMISSIONS FROM N IN URINE AND DUNG DEPOSITED BY GRAZING ANIMALS ON PASTURE, RANGE AND PADDOCK (TIER 1) FOR ANIMAL TYPE *T*

$$N_2O_{PRP(T)} = N_2O_{D,PRP(T)} + N_2O_{I,PRP(T)}$$

$$N_2O_{D,PRP(T)} = \left[\left(F_{PRP,CPP(T)} \bullet EF_{3PRP,CPP} \right) + \left(F_{PRP,SO(T)} \bullet EF_{3PRP,SO} \right) \right] \bullet \frac{44}{28}$$

$$N_2O_{I,RPR(T)} = F_{RPR(T)} \bullet \left[Frac_{GASM} \bullet EF_4 + Frac_{LEACH-(H)} \bullet EF_5 \right] \bullet \frac{44}{28}$$

EQUATION 10A.20 (NEW)
RELATIONSHIP BETWEEN AVERAGE ANNUAL NITROGEN FLOWS ASSOCIATED WITH AN INDIVIDUAL ANIMAL [KG N ANIMAL^{-1} YR^{-1}] AND THE ANNUAL NITROGEN FLOW FOR THE ANIMAL POPULATION OF LIVESTOCK CATEGORY/SPECIES *T* IN A COUNTRY [KG N YR^{-1}]

$$F = POP_{(T)} \bullet N$$

EQUATION 10A.21 (NEW)
TOTAL MANURE-N EXCRETED

$$N_{(T)} = N_{MMS(T)} + N_{PRP(T)}$$

EQUATION 10A.22 AND 10A.23 (NEW)
NITROGEN EXCRETION CALCULATED EITHER USING A DEFAULT FRACTION OF RETENTION (TIER 1) OR DIRECTLY FROM RETENTION DATA

$$Nex_{(T)} = N_{intake(T)} \bullet \left(1 - Frac_{RET(T)}\right)$$

$$Nex_{(T)} = N_{\text{int}ake(T)} - N_{RET(T)}$$

EQUATION 10A.24 (NEW)
TOTAL MANURE-N IN MANURE MANAGEMENT SYSTEMS

$$N_{MMS(T)} = \sum_{S} \left(POP_{(T)} \bullet Nex_{(T)} \bullet Frac_{S(T,S)} \right)$$

EQUATION 10A.25 (NEW)
MANURE-N MANAGED IN SYSTEM *S*

$$N_{mm\ (T,S)} = POP_{(T)} \bullet Nex_{(T)} \bullet Frac_{S(T,S)}$$

EQUATION 10A.26 (NEW)
MANURE-N DEPOSITED BY GRAZING ANIMALS, WITH X=CPP,SO

$$N_{PRP(X)} = POP_{(X)} \bullet Nex_{(X)} \bullet Frac_{S(X,G)}$$

EQUATION 10A.27 (NEW)
N IN BEDDING MATERIAL ADDED TO MANAGED MANURE

$$N_{bedding(T,S)} = POP_{(T)} \bullet N_{beddingMS(T,S)}$$

Where,

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

Annual total nitrogen flows, F, and annual average nitrogen flows per head, N:

$F_{(T)}$ and $N_{(T)}$ = animal manure nitrogen excreted for livestock species/category *T* in the country, kg N yr^{-1} and kg N animal^{-1} yr^{-1}

$F_{codigestate}$ = amount of nitrogen from co-digestates added to biogas plants, kg N yr^{-1}

$F_{MMS(T)}$ and $N_{MMS(T)}$ = animal manure nitrogen excreted for livestock species/category *T* in manure management systems in the country, kg N yr^{-1} and kg N animal^{-1} yr^{-1}

$F_{PRP(T)}$ and $N_{PRP(T)}$ = animal manure nitrogen excreted for livestock species/category *T* on pasture, range and paddock in the country, kg N yr^{-1} and kg N animal^{-1} yr^{-1}

$F_{PRP,CPP(T)}$ and $N_{PRP,CPP(T)}$ = animal manure nitrogen excreted for cattle, pig and poultry species/category *T* on pasture, range and paddock in the country, kg N yr^{-1} and kg N animal^{-1} yr^{-1}

$F_{PRP,SO(T)}$ and $N_{PRP,SO(T)}$ = total animal manure nitrogen excreted for sheep and other livestock species/category *T* on pasture, range and paddock in the country, kg N yr^{-1} and kg N animal^{-1} yr^{-1}

$F_{mm(T,S)}$ and $N_{mm(T,S)}$ = animal manure nitrogen excreted for livestock species/category *T* in manure management system *S* in the country, kg N yr^{-1} and kg N $animal^{-1}$ yr^{-1}

$F_{bedding(T,S)}$ and $N_{bedding(T,S)}$ = nitrogen in bedding material added for livestock species/category *T* in manure management system *S* in the country, kg N yr^{-1} and kg N in bedding $animal^{-1}$ yr^{-1}

$F_{AM(T,S)}$ and $N_{AM(T,S)}$ = annual amount of animal manure N applied to soils for each livestock species/category *T*, kg N yr^{-1} and kg N $animal^{-1}$ yr^{-1}

$F_{intake(T)}$ and $N_{intake(T)}$ = annual intake of N in feed for each livestock species/category *T*, kg N yr^{-1} and kg N $animal^{-1}$ yr^{-1}

$F_{retention(T)}$ and $N_{retention(T)}$ = annual retention of N each livestock species/category *T*, kg N yr^{-1} and kg N $animal^{-1}$ yr^{-1}

$F_{ex(T)}$ and $N_{ex(T)}$ = annual average N excretion of species/category *T* in the country, kg N yr^{-1} and kg N $animal^{-1}$ yr^{-1}

Annual N_2O emissions for the total population of each livestock species/category T

$N_2O_{(T)}$ = total annual N_2O emissions

$N_2O_{mm(T)}$ = total annual N_2O emissions from Manure Management for each livestock species/category *T* in the country, kg N_2O yr^{-1}

$N_2O_{D,mm(T)}$ = direct annual N_2O emissions from Manure Management for each livestock species/category *T* in the country, kg N_2O yr^{-1}

$N_2O_{G,mm(T)}$ = indirect annual N_2O emissions from volatilization of NH_3+NO_x from Manure Management for each livestock species/category *T* in the country, kg N_2O yr^{-1}

$N_2O_{L,mm(T)}$ = indirect annual N_2O emissions from leaching and run-off from Manure Management for each livestock species/category *T* in the country, kg N_2O yr^{-1}

$N_2O_{AM(T)}$ = total annual N_2O emissions from manure nitrogen applied to cultivated soils for each livestock species/category *T*, kg N_2O yr^{-1}

$N_2O_{PRP(T)}$ = total annual N_2O emissions from manure nitrogen deposited on pasture, range and paddock for each livestock species/category *T*, kg N_2O yr^{-1}

$N_2O_{D,AM(T)}$ = direct annual N_2O emissions from manure nitrogen applied to cultivated soils for each livestock species/category *T* in the country, kg N_2O yr^{-1}

$N_2O_{I,AM(T)}$ = indirect annual N_2O emissions from manure nitrogen applied to cultivated soils for each livestock species/category *T* in the country, kg N_2O yr^{-1}

$N_2O_{D,PRP(T)}$ = direct annual N_2O emissions from pasture, range and paddock for each livestock species/category *T* in the country, kg N_2O yr^{-1}

$N_2O_{I,PRP(T)}$ = indirect annual N_2O emissions from pasture, range and paddock for each livestock species/category *T* in the country, kg N_2O yr^{-1}

N_2O emission factors

EF_1 = emission factor for direct N_2O emissions from N inputs to cultivated soils, kg N_2O –N (kg N $input)^{-1}$

EF_{1FR} = emission factor for direct N_2O emissions from N inputs to flooded rice, kg N_2O –N (kg N $input)^{-1}$

$EF_{3PRP,X}$ = emission factor for direct N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N_2O –N (kg N input)$^{-1}$; X=CPP: Cattle, Poultry and Pigs; X=SO: Sheep and Other animals

$EF_{3(S)}$ = 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*)$^{-1}$

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 + NOx-N volatilised)$^{-1}$

EF_5 = emission factor for N_2O emissions from nitrogen leaching and runoff, kg N_2O -N (kg N leached and runoff)$^{-1}$

Fractions

$Frac_{S(T,S)}$ = fraction of manure N excreted that is managed in manure management system *S* for each livestock species/category *T*, dimensionless

$Frac_{S(X,G)}$ = fraction of manure N excreted that is deposited by grazing cattle, poultry or pigs (X=CPP) or sheep or other animals (X=SO), dimensionless

$Frac_{GasMS(T,S)}$ = fraction of managed manure nitrogen for livestock species/category *T* that volatilises as NH_3 and NOx in the manure management system *S*

$Frac_{LeachMS(T,S)}$ = fraction of managed manure nitrogen losses for livestock species/category *T* due to runoff and leaching during solid and liquid storage of manure in manure management system *S*

$Frac_{N_2MS}$ = fraction of managed manure nitrogen for each livestock species/category *T* that is lost in the manure management system *S*, percent as N_2

$Frac_{LossMS(T,S)}$ = total fraction of managed manure nitrogen for livestock category *T* that is lost in the manure management system *S*

$Frac_{GASM(T,S)}$ = fraction of applied organic N fertiliser materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilises as NH_3 and NOx, kg N volatilised (kg of N applied or deposited)$^{-1}$

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$

$Frac_{APPL(T)}$ = fraction of animal manure N available for application to managed soils which is applied to managed soils for each livestock species/category *T*, dimensionless

$Frac_{FEED(T)}$ = fraction of managed manure used for feed for each livestock species/category *T*, dimensionless

$Frac_{FUEL(T)}$ = fraction of animal manure N available for application to managed soils used for fuel for each livestock species/category *T*, dimensionless

$Frac_{CNST(T)}$ = fraction of animal manure N available for application to managed soils used for construction for each livestock species/category *T*, dimensionless

$Frac_{AM,Rice}$ = fraction of animal manure N applied to managed soils which is applied to flooded rice, dimensionless

$Frac_{RET}$ = fraction of feed intake N that is retained by the animal in body mass or livestock products for each livestock species/category *T*, dimensionless

Annex 10.B Data and Explanatory Text for Development of New Parameters in the *2019 Refinement*

10B.1 Raw data used to compile Annex 10A.1 enteric fermentation Tier 1 emission factors, volatile solids and nitrogen excretion for cattle and buffalo

A database was compiled from peer-reviewed articles, scientific and statistical reports found via a comprehensive literature search in google scholar (https://scholar.google.com) and Elsevier (www.sciencedirect.com) web search engines.

All raw data collected from literature sources and used as a basis by the IPCC authors to refine the final values presented in Tables 10A.1–10A.4 are available in the supplemental data supplied with this Chapter, maintained on the IPCC document website, there identified as Supplemental Information Chapter 10, Volume IV, *2019 Refinement*.

Since agricultural production systems of certain countries may be transitioning from low productivity local subsistence systems to higher productivity systems, the IPCC expert team of the *2019 Refinement* aimed to collect from a variety of literature sources published to date and report the final data differentiated by production system and performance parameters on cattle (dairy and non-dairy) and buffaloes for each world region.

It should be noted that the IPCC expert team assumed that such regions as North America, Western and Eastern Europe, and Oceania may be defined as regions where only high-production systems are in practice. However, Latin America, Asia, Africa, Middle East and Indian subcontinent experience transition period from low productivity local subsistence systems to higher productivity systems, hence, data on performance parameters and feeding situations of cattle and buffaloes reared in the two production systems were recorded by the IPCC expert team.

Moreover, the IPCC expert team of the *2019 Refinement* updated regional representation in Tables 10A.1–10A.4. The *2006 IPCC Guidelines* contain data aggregated performance parameters and enteric fermentation emission factors (EFs) for Africa and Middle East, however, values of nitrogen excretion rate (Nex) were presented separately for these regions, i.e. for Africa and Middle East. Hence, the IPCC expert team improved consistency in the reporting, and the team collected raw data and conducted the estimation of enteric fermentation EFs, Volatile solids (VS) and Nex rates for Africa and Middle East, separately, for the both productivity systems.

In addition, the IPCC expert team updated the representation of non-dairy cattle and buffalo sub-categories. Namely, the *2006 IPCC Guidelines* contain data on performance parameters, diets and feeding situations, and corresponding EFs, VS and Nex for three main sub-categories of non-dairy cattle (i.e., mature females, mature males and young), the 2019 *Refinement* contains data and corresponding EFs, VS and Nex for four main sub-categories: mature females, mature males, replacement and growing animals, and calves.

The majority of values determining performance parameters, diets and feeding situations in different regions of the world were updated by the IPCC expert team in the *2019 Refinement*. Namely:

To develop region-average performance parameters, diets and feeding situations of dairy and non-dairy cattle for *North America*, 12 peer-reviewed publications were examined by the IPCC expert team (Appuhamy *et al*. 2016; Basarab *et al*. 2005; Capper 2011; Dong *et al*. 2014; Jayasundara *et al*. 2016; Legesse *et al*. 2016; Mulliniks *et al*. 2017; Niu *et al*. 2018; Ominski *et al*. 2007; Sheppard *et al*. 2015; Stackhouse-Lawson *et al*. 2012; Waldrip *et al*. 2013). Final values relied on the expert judgement and consensus of the authoring team.

To update performance parameters, diets and feeding situation of dairy and non-dairy cattle reared in *Western Europe*, 7 peer-reviewed publications were examined by the IPCC expert team (Bannink *et al*. 2011; *Bannink et al*. 2016; FAO 2017; Gerrits *et al*. 2014; Hammond *et al*. 2016; Huuskonen 2017; Spek *et al*. 2013). Data determining diets and feeding situations for dairy and non-dairy cattle of Western Europe were updated; all performance parameters, with exception of milk yield per head of dairy cow, were carried over from the *2006 IPCC Guidelines*.

To deliver the regional-average final value on performance parameters, diets and feeding situation of dairy and non-dairy cattle of *Oceania*, 10 data sources were examined by the IPCC expert team (studies and datasets of statistical offices) were examined by the IPCC expert team (Australian Government Department of Climate Change 2006; Dairy Technical Working Group 2015; Fick 2016; Pickering & Wear 2013; Statistics NZ 2018a; Australian Bureau of Agricultural and Resource Economics and Sciences 2018; Dairy Australia 2018; Dairy NZ & LIC 2018; Statistics NZ 2018b). The final values (reported in Table 10A.1 and Table 10A.2) were refined based on data collected for Australia and New Zealand. Hence, the IPCC expert team encourages small Pacific Island nations to use enteric fermentation EFs, VS and Nex rates developed for Asian region, as productivity systems are more similar.

Overall, 35 data sources (scientific publications and statistical datasets) were examined by the IPCC expert team to obtain raw data on performance parameters, diets and feeding situations required to develop region-average final values for dairy and non-dairy cattle reared in *Eastern Europe* (Amerkhanov *et al.* 2016; Azaubaeva 2008; Bakharev 2012; Dunin *et al.* 2011; FAOSTAT 2017; Furaeva 2013; Gayirbegov & Mandjiev 2013; Golubkov 2015; Golubkov *et al.* 2015; Goncharova & Kibkalo 2011; Goncharova *et al.* 2009; Gren 2013; Gubaidullin *et al.* 2011; Haysanov 2011; Ilichev *et al.* 2011; IPCC 2006; Kalnickij & Haritonov 2008; Kostenko & Pyrozhenko 2012; Leontev *et al.* 2013; Levakhin *et al.* 2011; Litovchenko 2012; Mamaev *et al.* 2017; Nekrasov *et al.* 2013; Nosyreva Yu & Tokareva 2014; Pracht 2013; RUSSTAT 2016; Samorukov *et al.* 2013a; Samorukov *et al.* 2013b; Sharkaev & Kochetkov 2012; Sharkaeva 2012; Sharkaeva 2013; Sheveleva & Bakharev 2013; Shevkhuzhev *et al.* 2015; Tekeev & Chomaev 2011; Zadnepryanskiy & Zakirko 2012). Since Russian Federation, Ukraine and Belarus have the largest herd among other Eastern European countries (FAOSTAT 2017), the IPCC expert team focused mainly on the analysis of cattle management practice of these countries. Initial data for other Eastern European countries were taken from GLEAM model (FAO 2017). To make adjustment regarding the region-average final values reported in Table 10A.1 and Table 10A.2, the IPCC expert team considered the contribution of each country to the total dairy and non-dairy cattle population of Eastern Europe and corresponding parameters.

Raw data on cattle performance parameters, diets and feeding situations were distinguished between two production systems (i.e. low and high) of *Latin America* and collected by the IPCC expert team respectively. In total, 52 publications were examined by the IPCC expert team (Albarrán-Portillo *et al.* 2015; Albertini *et al.* 2012; Amaral *et al.* 2005; Ancco 2015; Ministerio de Ganadería 2017; Barajas Merchan *et al.* 2017; Barrantes 2000; Bartl *et al.* 2009; IPCC 2006; IBGE 2017; Becoña 2012; Ítavo *et al.* 2014; Cândido *et al.* 2015; Cardoso *et al.* 2017b; Castro *et al.* 2012; Chavez 2010; Ciudad de México Financiera Rural 2009; Cunha *et al.* 2016; Euclides & Medeiros 2003; FAO 2017; Huhn *et al.* 1982; Ítavo *et al.* 2014; Kolling *et al.* 2018; Lima *et al.* 2018; Machado Filho *et al.* 2014; Mariani *et al.* 2009; Mata e Silva *et al.* 2017; McManus *et al.* 2011; Medeiros *et al.* 2010; Modernel *et al.* 2013; Oliveira *et al.* 2014; Pajuelo Montalvo 2003; Pajuelo Montalvo 2008; Peres *et al.* 2012; Primavesi *et al.* 2004; Queiroz *et al.* 2011; Quispe *et al.* 2016; Reis 1998; Restle *et al.* 2003; Ribeiro *et al.* 2016; Rodriguez 2018; Rojas & Gómez 2005; Rosa *et al.* 2001; Ruiz & Sandoval 2014; Santos *et al.* 2011; Sgroi 2017; Silva *et al.* 2017; Simões *et al.* 2009; Teixeira *et al.* 2013; Teodoro & Madalena 2002; Teodoro & Madalena 2005; Verruma & Salgado 1994). Moreover, to clarify some parameters, the IPCC expert team conducted interviews with lead researchers of Latin America, namely: Sebastián Galbusera (Argentina); Dr. Pablo Soca, Faculty of Agronomy (Uruguay); Santiago Fariña, Dirceto of the Dairy Redearch Progmaram. National Institute of Agricultural Research (Uruguay); Dr. Laura Astigarraga, Faculty of Agronomy (Uruguay); Dr. Luiz Gustavo Ribeiro Pereira (Embrapa Dairy Cattle, Brazil); Dr. Pablo Soca, Faculty of Agronomy (Brazil). It should be noted that these above-listed publications were sources for initial data mostly for non-dairy cattle reared in Brazil, Uruguay, Peru and Argentina, and for dairy cattle husbandry practice applied in Brazil. However, initial data on performance parameters, diets and feeding situations applied for dairy cattle of other countries of Latin America were obtained from GLEAM model (FAO 2017). To adjust the final values recorded in Table 10A.1 and Table 10A.3, the dairy and non-dairy cattle population kept in each country of Latin America was taken into consideration by the IPCC expert team.

Performance parameters, diet and feeding situation of dairy and non-dairy cattle of the whole *Asian region* for low- and high-productivity systems were refined based on detailed data obtained from 50 publications (Alejandrino *et al.* 1999; Zi *et al.* 2003; Sutarno 2015; Hieu Vu *et al.* 2016; Widiawati *et al.* 2016; Gunawan & Jakaria 2011; Lapitan *et al.* 2008; Ramírez-Restrepo *et al.* 2017; Martojo 2012; Philippines Statistics Authority 2017; Moran 2012; Thanh 2014; Ichinohe *et al.* 2014; Dinh 2007; Department of Veterinary Services 2013; Panandam & Raymond 2005; Lam 2011; Gioi *et al.* 2012; Ariff *et al.* 2015; Waldron *et al.* 2015; Putra *et al.* 2015; Garcia *et al.* 2006; Zhai *et al.* 2006; FAO *et al.* 2014; Gerber *et al.* 2011; Xie *et al.* 2016; Cui *et al.* 2014; Yang *et al.* 2013; Xue *et al.* 2014; Dong *et al.* 2015; Zi *et al.* 2003; Huai *et al.* 1993; Ma *et al.* 2007; Ma *et al.* 2012; Wattiaux *et al.* 2002; Zhou 1998; Beldman *et al.* 2014; Xie *et al.* 2012b; Qiao *et al.* 2013; Dong *et al.* 2017; Han *et al.* 2016; Wang *et al.* 2014; Taneja 1999; FAO 2003; Wang *et al.* 2017; MAAR 2013; Hu & Zhang 2003; Gao *et al.* 2011; Cheng 1984; Gao *et al.* 2013). Raw data were obtained from the literature sources to determine parameters corresponding to low- and high-producing systems. Performance parameters of dairy and non-dairy cattle and their feeding systems were investigated for the following countries: China, Indonesia, Malaysia, Philippines and Vietnam. Moreover, the data of GLEAM model (FAO 2017) were used in a greater degree. A contribution of each country to the total cattle population of Asian region was considered by the IPCC expert team to adjust final values reported in Table 10A.1 and Table 10A.3.

Data on performance parameters, diets and feeding situations of dairy cattle reared in low- and high-productivity systems of *African region* were directly obtained from GLEAM model (FAO 2017). The model contains a compherensive dataset for the both types of productivity system applied in Kenya, Ethiopia, Uganda, Tanzania.

Moreover, performance parameters, diet and feeding situation of non-dairy cattle reared in the both productivity systems of African region were obtained as results of the analysis of 101 scientific articles and statistical reports (Abdel Rahman 2007; Abdelhadi & Babiker 2009; Abera 2016; Abraha *et al*. 2009; Addisu *et al*. 2010; Adebambo 2001; Adesina 2012; Ageeb & Hillers 1991; Ahamefule *et al*. 2007; Ahmed & Zubeir 2013; Ahmed Hassan 2010; Alemayehu *et al*. 2013; Ali *et al*. 2015; Alsiddig *et al*. 2010; Asimwe *et al*. 2015; Bashir & El Zubeir 2013; Bayemi *et al*. 2005; Behnke & Osman 2012; Blench 1999; Central Statistical Agency 2017; Chabo *et al*. 2003; Corbet *et al*. 2006; Dekeba *et al*. 2006; Du Toit *et al*. 2013; Edea *et al*. 2013; Elrshied & Ishag 2015; Engida *et al*. 2015; Essien 2003; Ethiopia F.D.R. 2011; FAO 2017; FAO & IAEA 2011; FAOSTAT 2017; Farmer & Mbwika 2012; Gebre Mariam *et al*. 2013; Goopy *et al*. 2018; Groeneveld *et al*. 1998; Gwaza & Momoh 2016; Haile *et al*. 2011; Halala 2015; Haren & Idris 2015; Ilatsia *et al*. 2011; International Livestock Centre for Africa 1977; Ismail *et al*. 2014; Kahi *et al*. 2006; Kanai & Zagi 2013; Kashoma *et al*. 2011; Kouazounde *et al*. 2015; Kubkomawa 2017; Kurwijila & Bennett 2011; Lukuyu *et al*. 2012; Lukuyu *et al*. 2016; Mai *et al*. 2012; Mandefro *et al*. 2017; Mapiye *et al*. 2011; Masama *et al*. 2003; Mekonnen *et al*. 2012; Ministry of Livestock and Fisheries Development of Tanzania 2014; Ministry of Livestock and Fisheries Development of Tanzania 2015; Mlote 2013; Mpofu 1996; Msanga *et al*. 2012; Muhuyi *et al*. 1999; Muriuki 2011; Musa *et al*. 2011; Mwambene *et al*. 2012; Mwambene *et al*. 2014; Mwanyumba *et al*. 2015; Myburgh *et al*. 2012; Nell 2006; Nell *et al*. 2014; Nouala *et al*. 2003; Nweze *et al*. 2012; Olorunnisomo 2013; Onono *et al*. 2013; Osman 1985; Pico 2004; Rakwadi *et al*. 2016; Raphaka 2008; Rege 1999; Rewe *et al*. 2006; Said *et al*. 2003; Salako 2014; Scholtz & Theunissen 2010; Shirima *et al*. 2016; Shittu *et al*. 2008; Siegmund-Schultze *et al*. 2012; Statistics Botswana 2016; Stein *et al*. 2009; Strous 2010; Strydom 2008; Strydom *et al*. 2000; Strydom *et al*. 2008; Tefera 2013; Tegegne *et al*. 2013; Temoso *et al*. 2016; Tesfa *et al*. 2016; Theunissen *et al*. 2013; Wurzinger *et al*. 2006; Young *et al*. 2005; Yousif & El- Moula 2006; Zerabruk & Vangen 2005). In addition to a rich dataset developed for low- and high-productivity systems, total population of non-dairy cattle of African region and contribution of the non-dairy population reared in each African country to the total (FAOSTAT (2017) was taken into consideration by the IPCC expert team to determine the final values on performance parameters, diet and feeding situation representative for the whole African region.

Overall, 24 publications were examined by the IPCC expert team to obtain raw data on performance parameters, diets and feeding situations of dairy and non-dairy cattle reared in low- and high-productivity systems of *Middle East* (Akbaş *et al*. 2006; Turkish Statistical Institute 2017; Karakok 2007; CBAT 2017; Chashnidel *et al*. 2007; da Cunha *et al*. 2010; Sadeghi-Sefidmazgi *et al*. 2012; FAO *et al*. 2014; Fatahnia *et al*. 2010; Gerber *et al*. 2011; IPCC 2006; Kamalzadeh *et al*. 2008; Kara *et al*. 2014; Karakok 2007; Koçyiğit *et al*. 2014; MFAL 2011; Sadeghi-Sefidmazgi *et al*. 2012; Statistical Centre of Iran 2011; Tasdemir *et al*. 2011; Ula 2016; USDA 2015; *Ustuner et al*. 2016; Özlütürk *et al*. 2006; Yalcin *et al*. 2017; Yilmaz *et al*. 2012). Due to an extend of contribution to the total dairy and non-dairy cattle population of Middle East, the focus of the IPCC expert team was made to investigate dairy and non-dairy cattle management practice applied in Turkey and Iran. The raw data obtained from literature sources for these two countries were adjusted to be a basis to evaluate the final values on performance parameters, diets and feeding situations representative for low- and high-productivity systems of the whole Middle East region.

Raw data on performance parameters, diets and feeding situations of low- and high-productivity systems applied for dairy and non-dairy cattle in *Indian subcontinent* were derived as a result of the analysis of 47 publications (Ahmad *et al*. 2004; Ahmad *et al*. 2013; Birthal & Parthasarathy Rao 2002; Boro *et al*. 2016; Bradfield & Ismail 2012; Chowdhry 2007; da Cunha *et al*. 2010; Department of Animal Husbandry 2013; Deshetti *et al*. 2016; Dhingra *et al*. 2017; FAO 2017; FAO *et al*. 2014; Garg *et al*. 2013; Gerber *et al*. 2011; IPCC 2006; Jabbar *et al*. 2009; Kayastha *et al*. 2008; Kenyanjui *et al*. 2009; Khan 2011; Khan *et al*. 2008; Khan *et al*. 2009; Khan *et al*. 2016; Landes *et al*. 2017; Mahakur *et al*. 2017a; Mahakur *et al*. 2017b; Manoj 2009; Moaeen-ud-Din & Bilal 2017; Nahar *et al*. 2016; National Bureau of Animal Genetic Resources 2017; Pathak *et al*. 2013; Patra 2012; Rahman *et al*. 2012; Rahman *et al*. 2015; Roy *et al*. 2016; Saha *et al*. 2004; Saha *et al*. 2012; Sambhaji 2013; Sarkar *et al*. 2006; Sharma *et al*. 2014; Singhal *et al*. 2005; Sirohi *et al*. 2012; Sodhi *et al*. 2007; Sontakke *et al*. 2014; Thombre *et al*. 2015; Tomar & Sharma 2002; Yadava 2009; Yasothai 2014). Taking into consideration, the largest contribution of cattle population of India, Pakistan and Bangladesh to the total dairy and non-dairy cattle population of the region, the main focus of the IPCC expert team was to collect and investigate low-productivity and high-productivity cattle farming of these countries. The final values reported in Table 10A.1 and Table 10A.3 were refined by the IPCC expert team based on consensus and were used to conduct estimations of enteric fermentation EFs, VS and Nex rates for dairy and non-dairy cattle in low- and high-productivity systems of Indian subcontinent.

Data to complete calculations of enteric fermentation emission factors, VS and nitrogen excretion rates for buffaloes were significantly updated in the *2019 Refinement* in comparison with the information reported in the *2006 IPCC Guidelines*. Namely, the *2006 IPCC Guidelines* report the initial data employed and corresponding EFs for two main regions: Indian subcontinent and Other regions. The IPCC expert team of the *2019 Refinement* extended regional representation and collected data for the same regions, which were applied to present EFs of cattle. Hence, data on buffalo performance parameters, diets and feeding situation for Western Europe, Eastern Europe, Latin America, Asia, Africa and Middle East were developed and reported in addition to presented dataset developed for Indian subcontinent. North America and Oceania were omitted from the reporting as according to the data presented in (FAOSTAT 2017), the regions do not have any buffalo husbandry practice. Moreover, region-average final values on performance parameters, diets and feeding situations were reported for four buffalo subcategories for all regions: mature males, mature females, growing and replacing animals and calves. The only exception was made for Indian subcontinent, where the final values were presented for five subcategories: breeding mature males, working mature males, mature females, growing and replacing animals and calves.

The IPCC expert team has decided not to distinguish performance parameter values, diets and feeding situation between low productivity and high-productivity systems implemented in buffalo husbandry across the world regions as it was conducted for dairy and non-dairy cattle, but to collect and report region-average values.

Overall, eight peer-reviewed publications were examined by the IPCC expert team to deliver performance parameters, diets and feeding situation of buffaloes kept in *Western Europe* (Borghese 2013; Condor *et al*. 2008; FAO 2005; FAO 2017; Gonzalez Gonzalez 2011; IPCC 2006; Neglia *et al*. 2014; Sabia *et al*. 2014; Zicarelli *et al*. 2007). Since Italy is a main contributor to the total buffalo population of Western Europe (FAOSTAT 2017), the buffalo husbandry practice of Italy was considered to be a representative for the whole Western Europe. However, data on buffalo performance parameters of Germany and Greece were also taken into consideration to adjust final values reported in Table 10A.4. The calculation of enteric fermentation EFs, VS and Nex rates were conducted based on Tier 2 method of the *2019 Refinement*.

To deliver data on performance parameters, diet characterisation and feeding situation of buffaloes of *Eastern Europe*, the focus in the research completed by the IPCC expert team was mainly made on investigation of buffalo husbandry implemented in Bulgaria and Romania. In total, 11 publications (i.e. case studies and statistical reports) were examined to complete a dataset needed to compute enteric fermentation EFs, VS and Nex rates (*Atanasov et al*. 2012; Borghese 2013; Dimov & Tzankova 2003; FAO 2005; FAOSTAT 2017; IPCC 2006; MZH 2016; MZH 2017; Nikolov 2011; Peeva *et al*. 2011; Peeva *et al*. 2013; Tzankova & Dimov 2003).

To develop a dataset on performance parameters, diets and feeding situation representing buffalo husbandry practice of *Latin America*, overall 25 studies were examined by the IPCC expert team (Andrade & Garcia 2005; Andrighetto *et al*. 2003; Andrighetto *et al*. 2003; Bailone *et al*. 2017; Cardoso *et al*. 1997; Cardoso *et al*. 2017a; Coelho *et al*. 2004; Damé *et al*. 2010; dos Santos *et al*. 2016; Gonçalves 2008; Jorge 2005; Jorge *et al*. 2002; Lima *et al*. 2014; Macedo *et al*. 2001; Maeda *et al*. 2007; Oliveira *et al*. 2009; Rassi *et al*. 2009; Rezende *et al*. 2017; Rodrigues *et al*. 2001; Sales *et al*. 2018; Santos *et al*. 2014; Zeoula *et al*. 2014; Tonhati *et al*. 2000; Tonhati *et al*. 2009; Verruma & Salgado 1994). Moreover, the IPCC expert team organized interviews with top researchers in this area to specify the findings and to cover lacking information from the scientific publications (Cristiana Andrighetto (UNESP-Dracena); Dr. José Ribamar Felipe Marques (Embrapa Amazônia Oriental)). In general, the final values recorded in Table 10A.4 for Latin America represent mainly characteristics of buffalo herd of Brazil, as the investigation of buffalo performance parameters reared in other countries of Latin America was not conducted by the IPCC expert team.

Overall, 42 publications (case studies and statistical reports) were examined by the IPCC expert team to derive raw data on buffalo performance parameters, diets and feeding situation of *Asian region* (Abd El-Salam & El-Shibiny 2011; Batosarnma 2006; Berthouly 2008; Carabao situation report 2017; Chang & Huang 2003; Cruz 2007; Cruz 2010; Cruz 2012; Das *et al*. 2004; Deb *et al*. 2016; Djaja 2011; Djajanegara & Diwyanto 2002; FAO 2003; FAO 2017; Flores *et al*. 2007; Han *et al*. 2007; Huai & Jun 1995; Kusnadi & Praharani 2009; Lambertz *et al*. 2014; Li *et al*. 2018a; Loculan 2002; Meyer *et al*. 2000; Mingala *et al*. 2017; Nanda & Nakao 2003; Nha *et al*. 2008; Phomsouvanh 2002; Prabowo 2012; Premasundera 2002; Qin *et al*. 2013; Qingkun *et al*. 2002; Riedel *et al*. 2012; Sanh 2007; Sivarajasingam 1987; Skunmun *et al*. 2002; Somapala 2002; Suryanto *et al*. 2002; Taneja 1999; Tuyen 2009; Van Sanh 2007; Wanapat & Rowlinson 2007; Yang *et al*. 2007; Yang *et al*. 2013a). The detailed analysis of buffalo husbandry practice applied in China, Indonesia, Laos, Philippines, Sri Lanka, Thailand and Vietnam was conducted to underlay for adjustment, based on consensus of the authoring team, of the final values of Table 10A.4.

According to the data reported (FAOSTAT 2017), only Egypt has population of domesticated buffaloes among other African counties. Hence, to deliver data on performance parameters, diets and feeding situation employed to compute enteric fermentation EFs, VS and Nex rates for buffaloes reared in *African region*, 22 publications determining Egyptian buffalo husbandry practice was examined by the IPCC expert team (Abd-Allah *et al*. 2015; Ali *et al*. 2009; Asheeri & Amal 2012; Ashour *et al*. 2007; Habeeb *et al*. 2016; FAO 2005; FAO *et al*. 2014; FAOSTAT 2017; Gerber *et al*. 2011; Habeeb *et al*. 2016; Hassan & Abdel-Raheem 2013; Ibrahim 2012; Ibrahim 2012; IPCC 2006; Khattab *et al*. 2011; Marai *et al*. 2001; Marai *et al*. 2009; Morsy *et al*. 2016; Presicce 2011; Radwan 2016; Shahin *et al*. 2010; Soliman 2009; WAAP 2007). Data on buffalo for other African countries were omitted from the analysis, the final values reported in Table 10A.4 and used in the calculations are relied on the expert judgement and consensus of the authoring team.

The analysis of 27 publications (case studies and statistical reports) resulted in evaluation of the region-average final values on performance parameters, diets and feeding situation of buffaloes husbandry for *Middle East* (Azary *et al.* 2007; Turkish Statistical Institute 2017; Çelikeloğlu *et al.* 2015; Chashnidel *et al.* 2007; DAD-IS 2017; Dezfuli 2010; Dezfuli *et al.* 2011; FAO 2017; FAO *et al.* 2014; FAOSTAT 2017; Gerber *et al.* 2011; GLEAM FAO 2017; Hossein-zadeh *et al.* 2012; IPCC 2006; Işik & Gül 2016; Jaayid *et al.* 2011; Mahmoudzadeh & Fazaeli 2009; Mahmoudzadeh *et al.* 2007; Manafiazar *et al.* 2007; Naserian & Saremi 2007; Porter *et al.* 2016; Şekerden 2013; Soysal 2013; Soysal *et al.* 2005; Tariq *et al.* 2013; Turkish Statistical Institute 2017; Yavuz & Zulauf 2004). Due to the availability and representation of publications, the focus of the IPCC expert team was mostly made on buffaloes reared in Tukey and Iran, the data collected for these countries were considered as a basis to made adjustment regarding region-average final values for Middle East reported in Table 10A.4.

To deliver initial data required to calculate enteric fermentation EFs, VS and Nex rates for buffaloes reared in *Indian subcontintent*, 37 publications (case studies and statistical reports) were examined by the IPCC expert team (Afzal *et al.* 2009; AGRI-IS 2017; Anitha *et al.* 2011; Anjum *et al.* 2012a; Anjum *et al.* 2012b; Basra & Nisa 2003; Breeding survey book 2013; Dahiya & Singh 2013; Dhingra *et al.* 2017; FAO 2017; FAO *et al.* 2014; FAOSTAT 2017; FICCI 2014; Gami *et al.* 2017; Garg *et al.* 2018; Gerber *et al.* 2011; Gupta *et al.* 2016; IPCC 2006; Jabbar *et al.* 2009; Jha *et al.* 2011; Khan *et al.* 2008; Khan *et al.* 2010; Khare & Baghel 2010; Kumar & Dass 2006; Kumar *et al.* 2011; Pathak 2005; Patra 2012; Prusty *et al.* 2016; Ranjhan 2007; Shahzad *et al.* 2011; Shekhar *et al.* 2010; Singal 2001; Singh 2002; Singh *et al.* 2012; Singh *et al.* 2015; Singh *et al.* 2017; Tariq *et al.* 2013; Tauqir *et al.* 2011). Data on performance parameters, diets and feeding situation of different breeds of buffaloes in India and Pakistan were adjusted to make the expert decision on the final values reported in Table 10A.4 and to conduct the calculations.

10B.2 Estimation of Cattle/Buffalo CH_4 conversion factors (Y_m)

Dairy Y_ms were developed considering summary statistics from the database consisting of results from 3,353 cows used in Niu *et al.* (2018) (Table 10B.1(New)) as well as data synthesis presented in the articles of Appuhamy *et al.* (2016), Hellwing *et al.* (2016) and Jayasundera *et al.* (2016). It was noted by the IPCC panel that these studies were not representative of global dairy systems and for that reason simple means developed through statistical analyses were deemed not to be reliable. Final values relied on the expert judgement and consensus of the authoring team. The summary statistics from Niu *et al.* (2018) are presented below (Table 10B.1), dividing that large data set into high, medium and low levels of milk productivity.

In the case of all productivity systems, clear differences were identified between the North American and the European feeding and production systems. The strongest contrasting factor was the proportion of neutral detergent fibre (NDF) in the diets of the two regions. Based on these summary statistics the Y_m is clearly driven by the relationship with NDF within the two regional production categories (Figure 10B.1).

To provide additional guidance for the selection of the methane conversion rates, NDF thresholds were established (Table 10B.1). For the highest production categories based on the North American and European statistics a low NDF <35 percent DMI and a high NDF >35 percent DMI categories were developed with values equivalent to 5.7 and 6.0 percent GEI respectively.

In the case of the values for the mid-range productivity, the value of 6.3 was determined assuming that NDF values were greater than 37 percent DMI as the values for medium and low producing animals from North America could not be considered to be representative of low production and lower quality diets. For countries that can clearly demonstrate that the NDF of their feed has been greater than 37 percent DMI, it is recommended to use the high production value that corresponds to the NDF content of the feed.

For low-productivity, the unweighted mean value of 6.5 from the European and North American data, consistent with the *2006 IPCC Guidelines* was selected. The panel did not consider that there was reliable data to modify the value from the *2006 IPCC Guidelines* value considering the very wide variety of diets that could be occurring globally for low productivity dairy cattle. However, it is proposed in the text that if dairy cattle are fed mainly on low quality forages countries are recommended to use the non dairy forage diet Y_m of 7.0.

Figure 10B.1 (New) Relationships between mean and median neutral detergent fibre (NDF) and methane conversion rate (Y_m) from summary statistics of Niu *et al.* (2018).

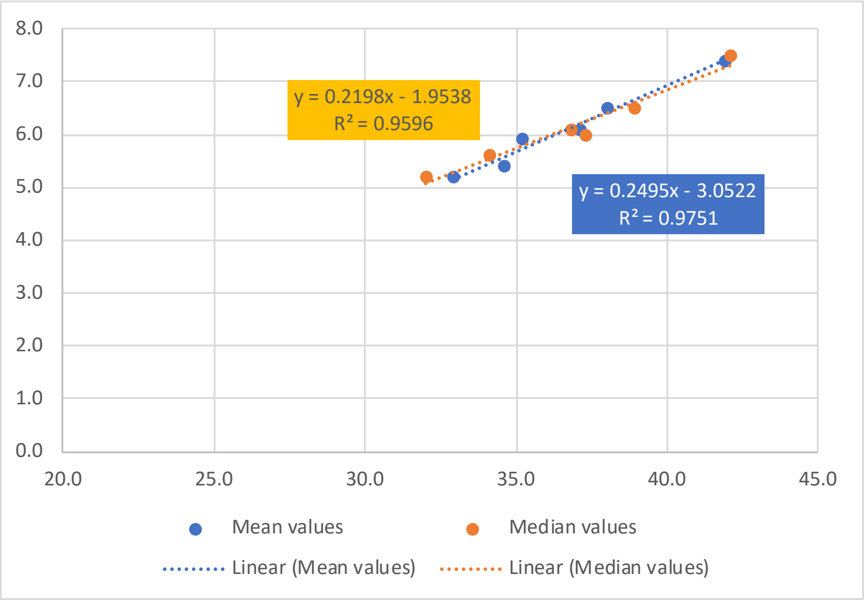


TABLE 10B.1 (NEW)
SUMMARY STATISTICS FROM NIU *ET AL.* (2018) DATABASE

Annual milk production grouping	All data			Europe			North America		
	<5000	**5000-8500**	**>8500**	**<5000**	**5000-8500**	**>8500**	**<5000**	**5000-8500**	**>8500**
Y_m median (%GEI)	6.3	6.0	5.7	7.3	6.4	6.0	5.9	5.5	5.2
Y_m mean (%GEI)	6.2	5.9	5.7	7.1	6.4	6.1	5.8	5.3	5.2
Y_m SD (%GEI)	1.3	1.2	1.1	1.0	1.1	0.9	1.2	1.1	1.04
Y_m unweighted mean (%GEI)	6.5	5.9	5.7	NA					
Annual milk production median (kg)	3,809	6,784	10,511	4,192	6,884	10,184	3,716	6,667	11,018
Annual milk production mean (kg)	3,619	6,783	10,840	4,036	6,849	10,538	3,483	6,709	11,245
Annual milk production SD (kg)	988	980	1706	740	965	1603	1,034	995	1,757
NDF median (%DM)	38	37	35	41	39	37	35	34	32
NDF mean (%DM)	37	37	35	41	38	37	34	35	33
NDF SD (%DM)	8.3	7.7	5.5	6.5	8.0	4.9	8.0	7.0	5.2
EE median (%DM)	2.8	3.0	3.9	3.5	3.4	3.9	2.5	2.7	3.8
EE mean (%DM)	2.9	3.2	3.8	3.4	3.4	3.9	2.6	2.9	3.8
EE SD (%DM)	0.8	1.0	1.1	0.7	0.9	1.0	0.8	1.2	1.2
Number of cows	551	1,392	1,410	165	814	805	326	556	604

Note: EE refers to ether extract an analytical method to estimate dietary fats and fatty acids

TABLE 10B.2 (NEW)
THRESHOLD CALCULATION BASED ON NDF CORRECTION

NDF	Mean	Median
32	5.08	4.93
33	5.30	5.18
34	5.52	5.43
35	**5.74**	**5.68**
36	5.96	5.93
37	**6.18**	**6.18**
38	**6.40**	**6.43**
39	6.62	6.68
40	6.84	6.93

In the case of beef cattle, a total of 113 measurements were compiled from 35 studies. Studies were divided by their dominant diet type into three categories, high forage diets, mixed diets (mixed forage and concentrate) and feedlot diets. Summary statistics were compiled and group averages are reported. Due to the variability in the data, values were rounded based on expert judgement. An overall average was developed for the feedlot and non-feedlot diets. Non feedlot diets were differentiated between dominantly forage based diets and mixed concentrate diets.

There is important variability in the results of studies that attempt to develop relationships between feed quality and methane yield. Nonetheless, numerous empirical and biochemical modelling studies demonstrate both the statistical significance and the biochemical processes that relate reductions in 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). For this reason, methane conversion rates are produced from a summary of low, medium and high dietary forage proportions. Raw data used in the development of these values are published in the IPCC TFI website.

TABLE 10B.3 (NEW)
SUMMARY OF DATA COMPILED FOR THE COMPILATION OF Y_M VALUES FOR CATTLE AND BUFFALO

Category	Measurement method	Average Body Weight (kg)	Methane yield (g/kg DMI)	SD (±)	Y_m (% GEI)	SD (±)	n
High forage	Chambers (24), SF_6 (30), Micro-meteorological (2)	451	23.0	4.6	7.2[1]	1.5	56
Intermediate forage	Chambers (17), SF_6 (7)	401	21.0	3.8	6.3	1.2	24
Feedlot (low forage)	Chambers (11), SF_6 (5), Head boxes (17)	450	12.99	3.3	3.84[2]	1.0	33

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); Doreau *et al.* (2011); Jordan *et al.* (2006a); Jordan *et al.* (2006b); Lovett *et al.* (2003); 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.* (2013a); Hünerberg *et al.* (2013b); Fiorentini *et al.* (2014); Hales *et al.* (2014); Hales *et al.* (2015); Romero-Perez *et al.* (2014); Troy *et al.* (2015); Romero-Perez *et al.* (2015); Nascimento *et al.* (2016); Vyas *et al.* (2016a); Vyas *et al.* (2016b); Baron *et al.* (2017); Hales *et al.* (2017).

[1] Rounded to 7.0 for Table 10.12.

[2] Rounded to 4.0 for Table 10.12.

10B.3 Estimation of Default Emission Factor(s) based on Goat Tier 2 parameters

A database was compiled from peer-reviewed articles that studied in-vivo methane (CH_4) production from goat enteric fermentation and N excretion. These studies were identified through a comprehensive literature search performed in Google scholar and ResearchGate and from sources that carried out review work such as a recent study attempting to derive statistical models for prediction of enteric CH_4 from goats (Patra & Lalhriatpuii 2016) and a New Zealand technical report for CH_4 and N excretion rates for goats (Lassey 2012). Data were directly extracted from the individual studies identified. Authors were contacted in order to fill in gaps of information from the studies.

Overall, 63 publications were obtained from a varied sample of countries and 18 different goat breeds (Aguilera *et al.* 1990; Prieto *et al.* 1990; Shibata *et al.* 1992; Haque *et al.* 1997; AFRC 1998; Haque *et al.* 1998; Islam *et al.* 2000; Islam *et al.* 2001; Rapetti *et al.* 2002; Puchala *et al.* 2005; Rapetti *et al.* 2005; Tovar-Luna *et al.* 2007b; Tovar-Luna *et al.* 2007c; Tovar-Luna *et al.* 2007a; Animut *et al.* 2008; Bhatta *et al.* 2008; Haque *et al.* 2008; Vermorel *et al.* 2008; Li *et al.* 2010; López *et al.* 2010a; López *et al.* 2010b; Tovar-Luna *et al.* 2010b; Tovar-Luna *et al.* 2010a; Gerber *et al.* 2011; López *et al.* 2011; Tovar-Luna *et al.* 2011; Abecia *et al.* 2012; Jeong *et al.* 2012; Lassey 2012; López *et al.* 2012; Mitsumori *et al.* 2012; Puchala *et al.* 2012a; Puchala *et al.* 2012b; Romero-Huelva *et al.* 2012; Yang *et al.* 2012; Bhatta *et al.* 2013; Chethan *et al.* 2013; López & Fernández 2013; Martínez-Fernández *et al.* 2013; Miri *et al.* 2013; López *et al.* 2014; Martínez-Fernández *et al.* 2014; Nielsen *et al.* 2014; Romero-Huelva & Molina-Alcaide 2014; Ibáñez *et al.* 2015a; Ibáñez *et al.* 2015b; Lu *et al.* 2015; Wang & Xue 2015; Arif *et al.* 2016; Castro-Lima *et al.* 2016; Criscioni & Fernández 2016; Lu *et al.* 2016; Patra & Lalhriatpuii 2016; Wang *et al.* 2016a; Wang *et al.* 2016b; Arco-Pérez *et al.* 2017; Barbosa *et al.* 2017; Keli *et al.* 2017; Kumar *et al.* 2017; Na *et al.* 2017; Romero-Huelva *et al.* 2017; Tovar-Luna *et al.* 2017; Azlan *et al.* 2018; Fernández *et al.* 2018; Li *et al.* 2018b; Na *et al.* 2018a; Na *et al.* 2018b; Puchala *et al.* 2018).

Although there was a total of 290 treatment means, treatments that were using substances with antimethanogenic properties were excluded before analysis. The minimum prerequisite for a study to be included in the data set was that Y_m values (or gross energy and CH_4 output energy) were reported.

Information on feed and diet characteristics, feed intake, breed, animal type, digestibility, and rumen were collected in the final data set. Table 10B.4 shows the mean and the range of some of the diet and animal variables for the different studies. Values were quite heterogeneous. For example, dry matter intake ranged between 0.14 and 2.51 kg DM intake/day animal (0.93 on average).

The concentrations of crude protein (CP), neutral detergent fibre (NDF) and starch were within the range of 6-26 percent (mean value of 15 percent), 18-74 percent (mean value of 42 percent) and 1-42 percent (mean value of 19 percent), respectively.

Methane production was expressed as grams per day, liters per day, megajoules per day, or as a proportion of GE or DE; therefore, the following factors were used in converting units: 1 g = 1.40 L =55.5 kJ; 1 L = 0.716 g = 39.54 kJ.

TABLE 10B.4 (NEW)
MEAN, MEDIAN, MAXIMUM, MINIMUM AND QUARTILE 1 AND 3 (Q1 AND Q3) VALUES FOR A SELECTION FEED DIET COMPOSITION, FEED INTAKE, BODY WEIGHT AND MILK PRODUCTIVITY

	Digestibility (%)					Feed intake			Body weight	Milk yield
	DM	**OM**	**N**	**NDF**	**GE**	**DM (kg/day)**	**GE (MJ/day)**	**DE (MJ/day)**	**kg/animal**	**(kg/day animal)**
Mean	68%	69%	72%	54%	71%	0.94	18.77	12.18	39.82	1.90
Median	69%	71%	73%	53%	72%	0.78	15.20	9.44	40.05	1.59
Max	83%	91%	84%	82%	83%	2.59	46.68	29.90	64.00	3.69
Min	49%	40%	44%	18%	52%	0.14	4.64	6.02	14.53	0.81
Q1	64%	65%	67%	46%	67%	0.62	11.80	8.44	33.45	1.31
Q3	74%	76%	78%	60%	76%	1.14	26.12	11.09	47.55	2.28

The CH_4 emissions also varied greatly in the dataset. Table 10B.5 shows the methane emissions expressed in different units and metrics.

TABLE 10B.5 (NEW)
MEAN, MEDIAN, MAXIMUM, MINIMUM AND QUARTILE 1 AND 3 (Q1 AND Q3) VALUES FOR CH_4 PRODUCTION RESULTS REFERRED AS A PROPORTION OF GROSS ENERGY INTAKE (CH_4 CONVERSION FACTOR: Y_M), DAY^{-1}, KG DM INTAKE^{-1}, KG OF MILK PRODUCED^{-1} AND KG OF BODY WEIGHT^{-1}

	CH_4				
	Y_m	*MJ/day*	*MJ/kg DM*	*MJ/kg milk*	*J/kg BW*
Mean value	5.3%	0.9	1.0	0.8	23.1
Median	5.3%	0.8	1.0	0.8	20.5
Max	10.3%	3.8	4.7	1.7	73.6
Min	1.2%	0.2	0.3	0.2	5.3
Q1	4.3%	0.6	0.8	0.6	15.8
Q3	6.3%	1.0	1.2	1.1	27.4

The average methane emission was 16.2 g CH_4/animal day, 18.3 g CH_4/kg DM intake, 0.42 g CH_4/ kg BW (*data not shown*). Average/median methane conversion factor (Y_m) was 5.3 percent, which is in the range of the recent value obtained by the study by Patra & Lalhriatpuii (2016), which included 42 studies.

We analyzed the relationship between methane output and diet type (e.g. diet digestibility, percent forage use) but there were no any clear statistical relationships between diet type and enteric methane output (*data not shown*). In general increased body weight and milk yield resulted in greater CH_4 output but body weight and milk yield did not show any statistical relationship with Y_m (*data not shown*).
Methane output per animal was positively correlated with dry matter (Fig 10B.2) and gross energy (Fig 10B.3) intake (R^2=0.60; P<0.00001).

Figure 10B.2 (New) **Annual enteric methane output per animal expressed in mass in relation to daily dry matter (DM) intake.**

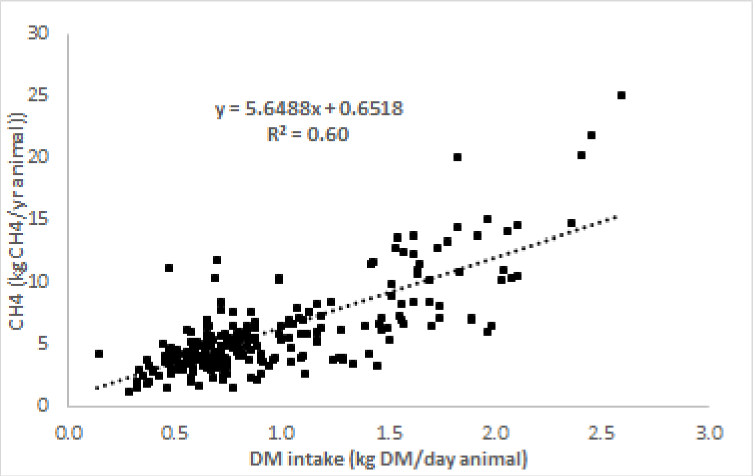
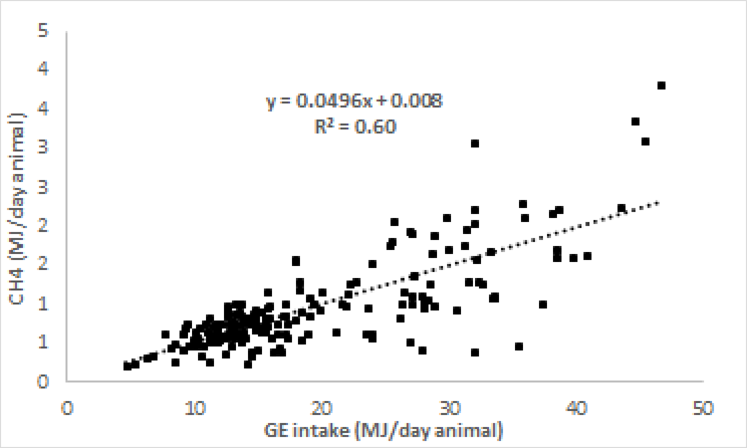


Figure 10B.3 (New) **Daily enteric methane output per animal expressed in energy in relation to daily gross energy (GE) intake.**



In order to develop Tier 1 EF for enteric CH_4 from goats for both low and high production systems the following steps were followed:

- Average goat weight (LW) for high and low production systems were estimated using global world information from Gerber *et al.* (2013). For high and low production systems it was estimated average weight values of 50 kg and 28 kg, respectively.
- Daily dry matter intake per animal was estimated as a function of animal weight using the equation from AFRC (1998).
- Using the equation from Fig 10B.2 we obtained kg CH_4/animal yr as a function of the previously estimated value of daily dry matter intake.

EF for Tier 1 resulted in 8.7 and 4.9 kg CH_4/head yr for high and low production systems, respectively. These values are both lower than those estimated in Vermorel *et al.* (2008) from French systems (11.9 kg CH_4/head yr^{-1}) and that for high production systems is similar to that proposed by Lassey (2012) for New Zealand goat herd.

Considering the data analysed, a Y_m of 5.5 percent has been chosen. No clear evidence was found to develop Y_m factors separately as a function of diet quality or production system.

In order to develop default values for N excretion rates (for Table 10.19) the following steps were followed:

Average goat weight (LW) for each global region were estimated using global world information from GLEAM FAO.

Daily N intake per animal and day was estimated as a function of average goat weight using the relationship developed from this database relating goat weight and N intake (Fig 10B.4) (R^2=0.48; P<0.00001).

Daily N excretion rate was subsequently calculated using the relationship also found using this database relating daily N intake and daily N excretion (Fig 10B.5) (R^2=0.89; P<0.00001) and transforming values to excretion rates espressed as kg N (1000 kg animal mass)$^{-1}$) day^{-1}.

Figure 10B.4 (New) **Daily N intake per animal expressed in relation to animal weight.**

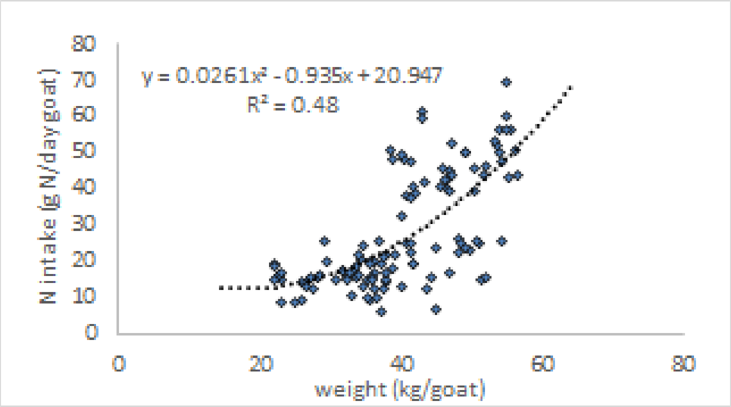
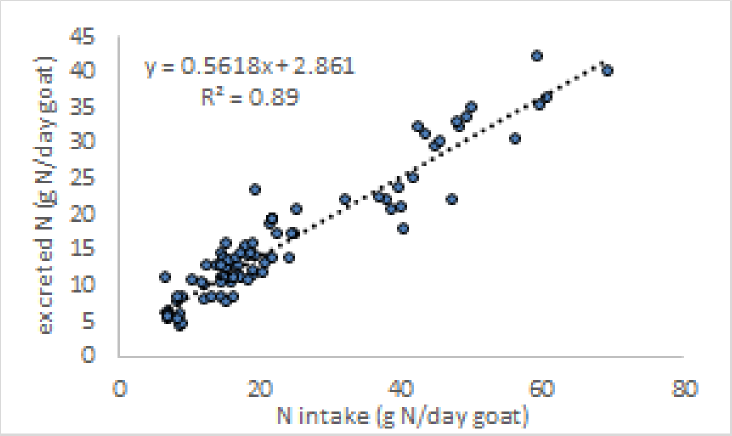


Figure 10B.5 (New) **Daily N excretion output per animal expressed in relation to daily N intake.**



In order to develop default values for volatile solids (VS) excretion rates (for Table 10.14A) we calculated daily VS excretion from goats for each world region according to equation 10.24. Gross energy intake was derived based on DM intake using the conversion factor 18.45 MJ/kg DM. We assumed that digestibility of the feed was 50 and 60 percent for developing and developed countries, respectively. The ash content of the feed was assumed to be 8 percent. We assumed the animal weights for each region based on information from FAO work: GLEAM FAO.

10B.4 Feed intake estimates using a simplified Tier 2 method

Prediction of DMI for cattle based on body weight and estimated dietary net energy concentration (NE_{ma}) or digestible energy values (DE percent):

Several studies have shown that dry matter intake (DMI) is highly and positively related to methane emissions. In some cases it has been reported that up to 92 percent of the variability in enteric methane emissions could be explained by DMI alone (Charmley *et al.* 2016). Most models developed to predict enteric methane emissions usually include either DMI or some form of feed intake. There are a number of models already developed with the objective of predicting DMI and these could be used in conjunction with emission factors to estimate enteric methane emissions in a Tier 2 approach. Appuhamy *et al.* (2016) evaluated 40 prediction equations using data that included measured DMI and feed quality attributes from North America, Europe and Australia/New Zealand. The best performing models in each region were then re-evaluated using calculated DMI and compared with estimates that used measured DMI. They evaluated several DMI prediction equations including the Cornell Net Carbohydrate and Protein System (CNCPS, Fox *et al.* 1992) as modified by Arnerdal (2005), National Research Council (NRC 2001) (developed based on North America cows), Lindgren *et al.* (2001) and Arnerdal (2005) (developed using data from cows in Europe), and Vazquez and Smith (2000) model (developed from Australia/New Zealand data). Appuhamy *et al.* (2016) reported that models using estimated DMI predicted enteric methane emissions just as good as the measured data and concluded that enteric methane emissions from dairy cows can be predicted successfully with estimated DMI, particularly using the modified CNCPS model. Appuhamy *et al.* (2018) further evaluated the comprehensive (IPCC-CMP) and simplified (IPCC-SMP) IPCC models (IPCC 2006) to predict DMI as well as the modified CNCPS and NRC (2001) models to predict DMI using an independent data. The modified CNCPS relying on BW and fat corrected milk yield (Eq. 1) more accurately predicted DMI (RMSPE = 14.1 percent) than NRC (RMSPE = 19.4 percent), IPCC-SMP (RMSPE = 16.9 percent), and IPCC-CMP (RMSPE = 23.4 percent). Overall, the results demonstrated that DMI of dairy cows can be predicted successfully using information such as milk yield, milk fat content, and body weight (BW) that are routinely available in dairy farms.

$$DMI\ (kg/d) = 0.0185 * BW\ (kg) + 0.305 * \text{fat corrected milk}\ (kg/d) \qquad \text{Eq [1]}$$

A simplified approach can also be used to estimate DMI of beef cattle, updated based on the most recent methodologies as described by NASEM (2017). For growing and finishing cattle, equations are:

Calves

$$DMI\ (kg/d) = (BW^{0.75} * (0.2435 * NE_{mf} – 0.0466 * NE_{mf}^2 – 0.1128)) / NE_{mf} \qquad \text{Eq. [2]}$$

Yearlings

$$DMI\ (kg/d) = (BW^{0.75} * (0.2435 * NE_{mf} – 0.0466 * NE_{mf}^2 – 0.0869)) / NE_{mf} \qquad \text{Eq. [3]}$$

Feedlot cattle (high grain diets)

Steers: $DMI\ (kg/d) = 3.830 + 0.0143 * BW * 0.96$ Eq. [4]

Heifers: $DMI\ (kg/d) = 3.184 + 0.01536 * BW * 0.96$ Eq. [5]

Where: BW = body weight (kg), NE_{mf} = Mcal/kg feed DM Eq. [6]

Mature Cows

Forage type	Digestibility	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

10B.5 Basis for Changes to MCF Calculations for Liquid/Slurry

The following briefly summarizes the *2006 IPCC Guidelines* approach and improvements included in the current approach.

2006 IPCC Guidelines Model for Liquid/Slurry:

The *2006 IPCC Guidelines* MCF for liquid slurry was based on the following relationship:

$MCF = f$

where f was calculated with the following temperature-dependent Arrhenius function, derived from Mangino *et al*. (2001), which is based on Safley & Westerman (1990):

$f = EXP[(Ea \times (T_2 - T_1))/(R \times T_2 \times T_1)]$

where,

f is a dimensionless fraction (0 to 1). Originally, Safley & Westerman (1990) used f to design an anaerobic digestion system at a lower temperature (T_2) based on known performance of a digester at a warmer temperature (T_1).

Ea is the activation energy. Originally, Safley and Westerman used Ea = 15175 cal/mol, based on an earlier study. Mangino *et al*. (2001) continued to use 15175 cal/mol.

T_2 is the variable temperature (K). Defined by Safley & Westerman (1990) as the unknown anaerobic digester temperature. Mangino *et al*. (2001) defined T_2 as the monthly temperature of the anaerobic lagoon (assuming equality with monthly average air temperature). The *2006 IPCC Guidelines* defined T_2 as the annual average temperature of a region.

T_1 is the reference temperature (K). Defined by Safley & Westerman (1990) as 30 °C (303.16 K). Mangino *et al*. (2001) and the *2006 IPCC Guidelines* use the same value.

R is the gas constant 1.987 cal k^{-1} mol^{-1}.

The reasons for modification of MCF, though the Methane conversion factor (MCF) remains an uncertain parameter.

First and foremost, in the *2006 IPCC Guidelines*, the MCF parameter violates a first-principle of inventory development: comparability. The use of an annual average temperature to calculate MCF systematically underestimates the annual MCF due to the mathematical principle known as Jensen's Inequality which applies to non-linear functions such as the Arrhenius equation (VanderZaag *et al*. 2018). Using this mathematical principle it can be shown that for a 1-month retention time, the annual average MCF calculated based on monthly temperature will always exceed the MCF calculated from the annual average temperature. Therefore, the *2006 IPCC Guidelines* MCF values are underestimates, and the level of underestimation is greatest for countries with large seasonal temperature extremes.

The model in the *2006 IPCC Guidelines* also used a management and design practices (MDP) factor which reduced the mass of VS entering the manure storage or lagoon. Since VS cannot simply vanish, there needs to be justification for altering the VS loading rate. In the modified method, the MCF calculation used an MDP = 1.0, which means we are assuming the VS Excretion rates are correct, and that VS Excreted enters the liquid manure storage. MDP factors may be used in specific cases such as when solid-liquid separation systems are used, whereby VS is removed from the liquid system and transferred to a solid system. However in most cases the use of MDP factor is indicative of an inaccurate B0 or VS input into the manure storage system.

For the sake of completeness, it is worth pointing out that the quantity of VS entering liquid storage could be greater than VS excreted (implied MDP >1.0). For instance, the use of straw bedding results in additional VS entering the liquid storage. Another example is waste milk (from treated cows, or from cleaning milking systems) on dairy farms which adds VS to the storage. Secondly, it is well known that the retention time of liquid manure in storage is a critical parameter in determining MCF, and the *2006 IPCC Guidelines* state "both temperature and retention time play an important role in the calculation of MCF". However, the *2006 IPCC Guidelines* calculations of MCF (Table 1), give very little focus to retention time. Previous *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (GPG2000)* recommended that future MCFs be modelled accounting for the storage period (Zeeman & Gerbens 2000). Furthermore, the work of Safley & Westerman (1990) showed that the same amount of VS destruction can be achieved by longer retention time at lower temperature compared with shorter retention time at higher temperature. Furthermore the suggestion to use formula 1 for batch-fed storage/digesters that is currently in *2006 IPCC Guidelines* would not result in a value that is comparable to the default annual temperature values, because this equation would inherently require inclusion of retention time.

Recent year-round field studies in climates where the annual average air temperature was <10°C have reported MCFs in the range of 0.61 (Wightman & Woodbury 2016) , ≥0.57 (Balde *et al.* 2016a) at liquid/slurry dairy manure storages, and greater for anaerobic lagoons (Leytem *et al.* 2017). Controlled studies at or around 20°C without added inoculum reported MCF of 55 percent over 165 d (VanderZaag *et al.* 2010) and 32 percent over 150-d (Masse *et al.* 2008). Another study showed the MCF increased non-linearly with the duration of storage (Le Riche *et al.* 2016). Previous IPCC Guidance reported an MCF of 39 percent, 45 percent, and 72 percent for liquid/slurry for Cool, Temperate, and Warm climates, respectively (Zeeman & Gerbens 2000). They also stated that liquid/slurry storage tanks were considered to have ≥6 month retention time. Therefore, the interaction between retention time and temperature has long been recognized, but the calculation of MCFs has not been fully transparent about how this important interaction has been handled (or how it should be handled by practitioners) and therefore has made comparability with measurements challenging.

Thirdly, the single temperature time step given in the IPCC guidelines suggests a level of certainty that is simply not supported by the experimental results, considering the approach being used.

TABLE 10B.6 *2006 IPCC GUIDELINES* TABLE OF MCF VALUES FOR LIQUID/SLURRY (TABLE 10.17)

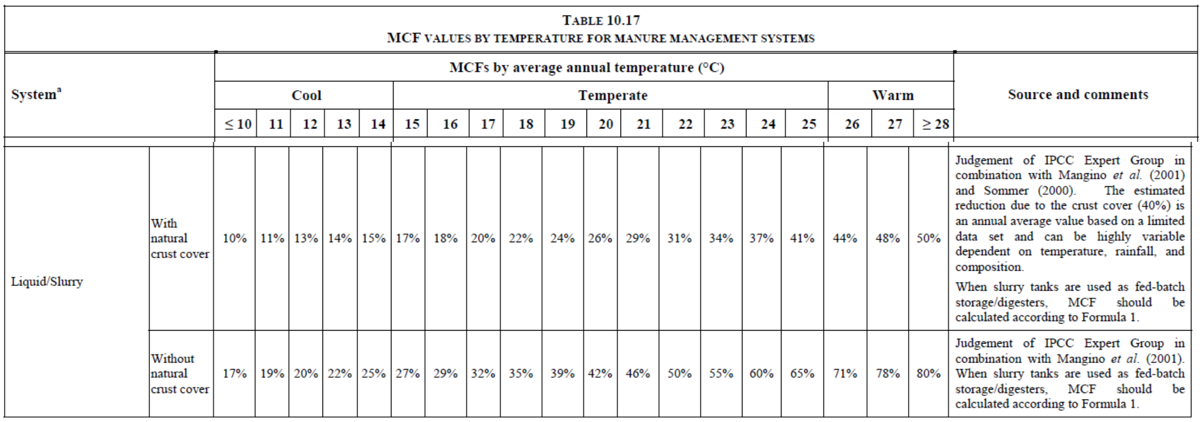


TABLE 10.17
MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS

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

Proposed Changes:

The proposed change is to use a spreadsheet model to calculate MCF using monthly temperature in each IPCC climate region, and for a specific liquid manure retention time (e.g. the table below). Therefore, this approach produces MCF values that account for both temperature and retention time, while leaving the users to decide which retention time is appropriate for their manure management systems. The spreadsheet model <*Vol4_Ch10_ MCF_Calculation-Spreadsheet*> for calculation of country-specific MCFs is available at *https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/Vol4_Ch10_%20MCF_Calculation-Spreadsheet.xlsx*.

TABLE 10B.7 (NEW)
MCFS CALCULATED FOR EACH RETENTION TIME AND CLIMATE (SELECTED IPCC CLIMATE REGIONS SHOWN)

RETENTION TIME	Tropical Montane	Tropical[1] Wet	Tropical[1] Moist	Tropical[1] Dry	Warm Temperate Moist	Warm Temperate Dry	Cool Temperate Moist	Cool Temperate Dry
1 Month	0.25	0.38	0.36	0.42	0.13	0.15	0.06	0.08
3 Month	0.43	0.61	0.57	0.62	0.24	0.28	0.12	0.16
4 Month	0.50	0.67	0.64	0.68	0.29	0.32	0.15	0.19
6 Month	0.59	0.76	0.73	0.74	0.37	0.41	0.21	0.26
12 Month	0.73	0.80	0.80	0.80	0.55	0.64	0.31	0.42
T_{avg} C	21.5	25.9	25.2	25.6	13.9	14.0	4.6	5.8

[1] Note that an upper limit MCF of 80% has been imposed for consistency with the anaerobic lagoon MCFs at high temperatures and long retention times

Changes in liquid/slurry MCF, compared to the 2006 IPCC Guidelines are summarized below:

#1 – Timestep:

Monthly temperature (proposed) instead of annual average temperature (IPCC 2006)

Methane emissions are non-linearly related to temperature, therefore Jensen's inequality states that the use of the average temperature will lead to systematic underestimation. As a result, monthly average air temperature is proposed for the calculation of MCF, rather than annual average temperature. Therefore, it is proposed that MCF for liquid/slurry be calculated using the Mangino *et al.* (2001) spreadsheet model, with the regional climate data from the IPCC defined climate regions. Additional details below.

#2 – Retention Time:

Several retention times (proposed) instead of 1-month implied retention time (IPCC 2006)

Retention time is a crucial parameter determining the extent of methane emissions and the quantity of VS in storage at any given time, therefore affecting the MCF. The *2006 IPCC Guidelines* used a 1-month retention time for all liquid/slurry systems by using MCF = *f*, based on an annual average temperature. Using a 1-month retention time is unrealistic, since the majority of liquid/slurry storages are meant for storage over several months or more. Therefore, it is proposed to calculate MCF based on five retention times: 1 month, 3 months, 4 months, 6 months, and 12 months.

Proposed "*good practice*" in the case of countries that do not have information on retention times is to use the six month retention time.

#3 – Activation Energy (Ea):

Updated Ea value (19347 cal/mol proposed) instead of 15175 cal/mol (IPCC 2006)

Recent research from Petersen *et al.* (2016) and Elsgaard *et al.* (2016) propose a new Ea value of 81 kJ/mol = 19347 cal/mol. It is proposed to use this updated value.

#4 – Reference Temperature (T_1):

Updated T1 value (308.16 proposed) instead of 303.16 K (IPCC 2006)

The value of T_1 used by *2006 IPCC Guidelines* and Mangino *et al.* (2001) is directly taken from Safley & Westerman (1990). The original intent of Safley and Westerman was comparing performance of a known and unknown anaerobic digester performance. In Mangino *et al.* (2001) and the *2006 IPCC Guidelines* the value of T1 defines the temperature at which $f = 1.0$, therefore T1 defines the temperature at which the B_0 will be reached in one month. There is considerable literature on laboratory methods for incubating manure to measure methane potential (e.g. BMP, B_0) and it is customary for the temperature of these incubations to be ca. 35°C, rather than 30°C. With a temperature of 35°C it would be reasonable to expect the B_0 to nearly be reached in 30 days (i.e. one month) (e.g. Owen *et al.* 1979; Pham *et al.* 2013). Therefore, it is proposed to change T_1 to 308.16 K (=35 + 273.16).

#5 – Manure Temperature (T_2):

Manure temperature lagging behind T_{air} (proposed) instead of equal T_{air} (IPCC 2006)

Most of the time, manure temperature does not equal air temperature. The temperature of liquid manure tends to lag behind air temperature. While models for manure temperature do exist (Rennie *et al.* 2017) this is too complex for the general guidelines. As a pragmatic alternative, a 1-month lag is proposed, i.e., set $T_2 = T_{air}$ from the previous month. It has also been shown (Rennie *et al.* 2018) that manure storages which are emptied once per year at the end of the growing season before winter stay cooler than air temperature during the summer. Therefore, only in the case of once per year emptying (i.e. 12 month retention time), a downward temperature shift of 3°C has also been applied.

#6 – VS carryover after emptying:

After manure is removed, 5 percent remains (proposed), instead of complete emptying (IPCC 2006)

It has been shown in several studies that farms do not completely empty liquid/slurry storages due to the practical challenge of doing so at the farm-scale (Balde *et al.* 2016b). Therefore, it is proposed that 5 percent of VS is retained in storage after emptying, rather than 0 percent (i.e. completely clean) assumption implied in the *2006 IPCC Guidelines* calculations. It is noteworthy that the IPCC 2000 *Good Practice* Guide (Zeeman & Gerbens 2000) mention approximately 15 percent of the manure storage cannot be emptied.

10B.6 Revision of methane from dung deposited onto pasture range and paddocks (Table 10.17)

Dataset

Cai *et al.* (2017) included 26 data, however some of these were omitted due to incomplete information to allow an estimation of methane conversion factor (MCF) and/or emission factors on the basis of volatile solids (VS) content. Therefore, the number of values retained was 20. Our review of the literature identified a further 25 suitable values (Carran *et al.* 2003; Saggar *et al.* 2003; Sherlock *et al.* 2003b; Sherlock *et al.* 2003a; Kelly *et al.* 2016), resulting in a total of 45 data values spanning six countries (Table 10B.8). Data were available for dairy cattle (25), beef cattle (9), sheep (8) and yaks (3). Data was assessed for suitability, in terms of length of study, sufficient replication and inclusion of key manure characteristics to allow estimation of the emission factors (g CH_4/kg VS; Table 10B.9) and MCF (percent; Table 10.17). Some studies also presented emissions on the basis of mass of CH_4 emitted per unit of faecal dry matter (FDM). Therefore, we have also supplied emission factors using these units (g CH_4/kg FDM) for countries with access to total FDM (Table 10B.9).

TABLE 10B.8 (NEW)
REGIONAL DISTRIBUTION OF DATA USED TO DERIVE MCF AND METHANE EF FROM EXCRETION VOLITILE SOLIDS DATA ON PRP

Country	Cattle	Sheep	Total
Australia	13		13
Brazil	4		4
China	3	2	5
Japan	5		5
New Zealand	6	6	12
UK	6		6
Total	**37**	**8**	**45**

Emission factors

Methane conversion factors (MCF) and emission factors were estimated for both cattle and sheep, where yaks were grouped with cattle (Table 10B.9). For estimating MCFs and emission factors based on VS content, ash content of dung is required. We estimated dung ash content to be 17.9 percent for pasture-fed sheep, beef cattle and dairy cattle (Fries *et al.* 1982; Karn 1991; Waghorn *et al.* 1999; Andueza *et al.* 2017). Data from a UK study (Defra, 2014) suggested that the IPCC B_0 values were appropriate for cattle, we therefore assumed the IPCC values for sheep were also reasonable estimates. For yaks, we used the IPCC default B_0 value for buffalo (0.100).

There was no significant difference in values for cattle and sheep regardless of the method of representing methane emissions ($P > 0.05$). For the refinement of the *2006 IPCC Guidelines* we therefore suggest an aggregated value is used. We also explored the possibility of disaggregating EF values by climatic zones, however the limited size of the dataset did not support this. Therefore, an aggregated value regardless of temperature is suggested for the refinement.

When adopting a Tier 2 approach, the MCF must be used in conjunction with a single B_0 value of 0.19 m^3 CH_4 kg^{-1} of VS excreted to ensure consistency with the Tier 1 emission factor provided in Table 10.14.

TABLE 10B.9 (NEW)
METHANE CONVERSION FACTOR (MCF) AND METHANE EMISSION FACTORS (PER KG FAECAL DRY MATTER (FDM)) AND VOLATILE SOLIDS (VS) FOR CATTLE AND SHEEP

Livestock species	MCF (%) Average, (Std Dev)	EF (g CH_4/kg FDM) Average, (Std Dev)	EF (g CH_4/kg VS) Average, (Std Dev)
Cattle	0.46 (0.38)	0.49 (0.42)	0.59 (0.51)
Sheep	0.52 (0.40)	0.53 (0.42)	0.65 (0.51)
Average	**0.47 (0.38)**	**0.50 (0.42)**	**0.60 (0.51)**

10B.7 Estimation of default values for MCFs, EFs for direct N_2O emissions, NH_3 and N_2 volatilized as well as NO_3 leached from solid storage and composting systems

Methodologies

The estimation of updated MCF values, EF for direct N_2O emissions and NO_3 leaching and N_2 from both (i) solid storage and (i) two composting systems (static pile and passive windrow) are based on an extensive meta-analysis of 50 peer-reviewed research articles involving 304 observations and published in open access by Pardo *et al.* (2015). In this study it was quantified the response of GHG emissions, NH_3 emissions, and total N losses to different solid waste management strategies (conventional solid storage, turned composting, forced aerated composting, covering, compacting, addition/substitution of bulking agents and the use of additives).

For solid storage, new treatments have been proposed to be incorporated in the *2019 Refinement*: covering/compacted (both treatments had similar effects on GHG emissions), addition/substitution of bulking agents and the use of additives. In the *2006 IPCC Guidelines for National GHG inventories* default emission factors for solid storage were based on expert IPCC judgement and a single study (Amon *et al.* 2001). In Pardo *et al.* (2015) the estimation of MCF values and EF for direct N_2O emissions from solid storage (without treatment) is based on data from 30 studies at the farm level.

For the new treatments, MCF values and EFs for direct N_2O emissions have been based on:

- 9 studies for compacting and covering;
- 11 studies for addition/substitution of bulking agents;
- 6 studies for use of additives.

For the rest of the management systems, MCF values and EF for direct N_2O emissions have been based on:

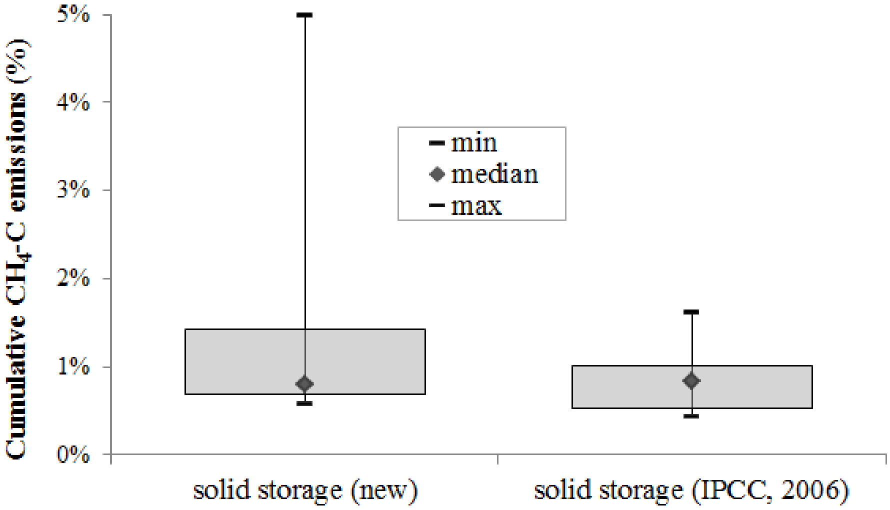
- 22 studies for solid storage;
- 6 studies for composting-static piles (Forced aeration);
- 11 studies for composting-Passive windrow (infrequent turning).

Based on the *2006 IPCC Guidelines* climate zone classification two factors were defined: Temperature, which involved two categories (i) Warm temperate and (ii) Cool temperate; and annual rainfall rate, including (i) Dry, (ii) Moist and (iii) Wet conditions.

CH_4 MCF

For the absolute CH_4-C emission values, Pardo *et al.* (2015) used untreated solid storage as a reference system. They compared estimated percent C lost as CH_4 using the *2006 IPCC Guidelines* method (IPCC 2006 MCF) with the values obtained at the different studies (Figure 10B.6).

Figure 10B.6 (New) Comparison between ranges of CH_4-C emissions observed in collected studies in Pardo *et al.* (2015) (new) with estimations for the same studies according to the *2006 IPCC Guidelines* methodology. Figure adapted from Pardo *et al.* (2015).



For untreated solid storage systems Pardo *et al.* (2015) showed that overall values were within the *2006 IPCC Guidelines* range for CH_4 emissions (Figure 10B.6) and confirmed that the differences between cold and temperate conditions were in agreement with those indicated by the *2006 IPCC Guidelines* not shown here, Figure S3b in Pardo *et al*. (2015). There were not enough studies under warm conditions and therefore, the assumption is to keep the same values indicated by the *2006 IPCC Guidelines*.

Values for new solid storage treatments and composting (static pile and passive windrow) are estimated using the reference value from the untreated solid storage system and the relative differences observed in Pardo *et al*. (2015).

For the new treatments, covering or compacted solid storage resulted in emissions in the same range as in solid storage not shown here, Figure 2b in Pardo *et al*. (2015) and estimated reduction of 75 percent and 50 percent was observed due to bulking agent addition and additives, respectively not shown here, Figure 2b in Pardo *et al*. (2015). The differences amongst climatic zones were assumed to be in the same proportion as that found for untreated solid storage systems.

Both composted static piles and static windrows were estimated to produce 50 percent of the CH_4 emitted from solid storage not shown here, Figure 2b in Pardo *et al*. (2015), which results in consistently greater values than those indicated by the *2006 IPCC Guidelines*. As a difference to the *2006 IPCC Guidelines*, CH_4 emissions were found to be temperature dependent for both composting systems (*2006 IPCC Guidelines* did not indicate temperature differences for static piles).

N_2O EF3 (Table 10.21)

According to the data examined in Pardo *et al.* (2015), there was no evidence to assume a lower EF for solid storage systems (0.005 kg N_2O–N kg^{-1} N excreted) than for passive windrow composting (0.01 kg N_2O–N kg−1N excreted). In fact, an EF of 0.5 percent (0.005kg N_2O-N kg initial N^{-1}) and 1 percent (0.01kg N_2O-N kg initial N^{-1}) were found for composting-passive windrow and solid storage, respectively.

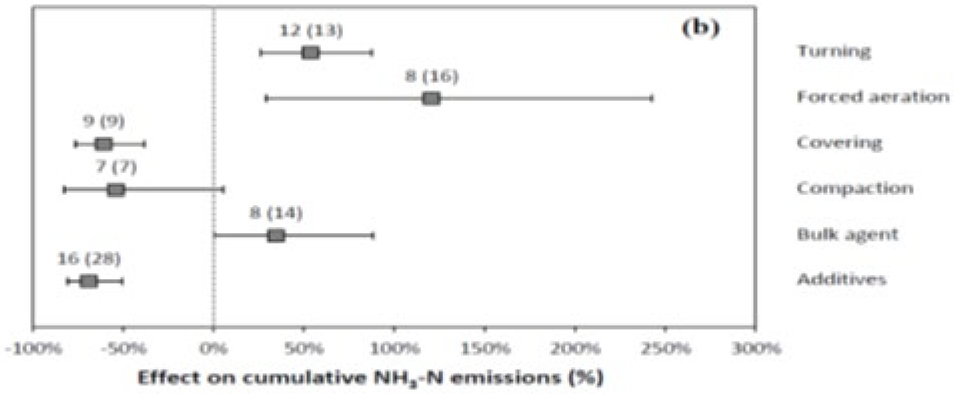
Composting static pile, in contrast to the *2006 IPCC Guidelines*, was found to emit greater N_2O emissions than passive windrows (not shown here, Fig. 3a in Pardo *et al*. 2015).

For the different treatments of solid storage, whereas Pardo *et al.* (2015) found no different effect on N_2O after compaction or covering, for both the addition of bulking agents or additives, a reduction of about 50 percent compared with conventional solid storage was observed not shown here, Figure 2a in Pardo *et al.* (2015).

NH_3 losses

For solid storage and composting relative values compared to solid storage reflect results obtained from meta-analysis by Pardo *et al.* (2015) (Fig 10B.7). Ammonia and NO_x default values in Table 10.22 for conventional solid manure storage and other systems defined both in IPCC Guidelines and EMEP/EEA (2016) have been taken from current EMEP/EEA air pollutant emission inventory guidebook 2016. EFs from EMEP/EEA (2016) values, which are expressed per TAN excreted and for each of the phases of the manure management, have been recalculated to be expressed as a funtion of total N excreted considering the mass balance flow between the different manure management phases prior to manure application (housing, yards and storage). For other categories not present in EMEP/CORINAIR (2016), first for stages prior to storage, we have estimated percent N lost using default EMEP/CORINAIR EFs for conventional manure storage and assuming no N_2O or N_2 losses, and subsequently, during storage, we used the relative effect between solid storage and the alternative solid storage categories (e.g. composting) (Fig 10B.7) as the basis to estimate NH_3+NO_x EF during storage.

Figure 10B.7 (New) Effect on cumulative NH_3-N emissions of different solid storage and composting methods compared with conventional solid storage. Figure adapted from Pardo *et al.* (2015)



NO_3 leaching and N_2 losses

Nitrate leaching/run-off has been estimated from the database from Pardo *et al*. (2015). For solid storage and composting some of the studies included measurements of N leaching (15), some of which estimated N_2 from the total N balance, but only one included measurements of N_2 (Moral *et al*. 2012). As a median value about 3 percent is estimated to be lost as NO_3 leaching/run-off (range: 0-38 percent). This value is subject to large uncertainty. In fact these trials may not represent common practices where the efficiency of collection of excreta N is much lower and can lead to as great as 50 percent losses (e.g. Lekasi *et al*. 2001; Rufino *et al*. 2007). Nitrogen (N_2) losses, have only been, to our knowledge, measured by Moral *et al*. (2012) (12 percent) and even though they could be estimated as a result of an N balance from trials where all N flows except N_2 have been measured, the results are very uncertain (0-55 percent). For N_2, an estimated median value of 12 percent was found; coinciding with the measured value by Moral *et al*. (2012). Systems that do not percolate but are subject to large water input will have greater N_2 losses and lower NO_3 leaching-runoff. The opposite effect will be expected with rainy areas with no containment and large possibilities for run-off/leaching. Values must be considered with large caution.

A further summary review was carried out to identify run-off/leaching values from dry lots and manure pack. As observed in the *2006 IPCC Guidelines* runoff and leaching values varied greatly citing ranges of 3 to 6 percent of N excreted (Eghball & Power 1994) or 5 to 19 percent (Bierman *et al*. 1999). In humid environments losses can be significant reaching 22-25 percent (Uusi-Kämppä 2002). However, uncovered holding and feeding pens without runoff containment tend to be in drier climates simply due to challenges in moisture control in more humid environments. Furthermore, considerable numbers of cattle are raised in drier climates and as a result considerably more studies exist looking at runoff from feedlots and drylots. Likewise recent attempts have been made to attempt to model these losses to the environment (Kizil *et al*. 2006; Williams et al. 2006). These studies tend to place the range of runoff loss between 1 percent and roughly 7 (Kizil *et al*. 2006; Erickson & Klopfenstein 2010; Vadas & Powell 2013). It is proposed the value of 3.5 percent with an uncertain range of 0 to 7 percent be considered as a default leaching factor for open, uncovered, uncontained drylots and bedded pack to provide a Tier 1 estimate of the fraction of N excreted lost to the environment.

Inventory compilers must be careful to consider that this refers to N lost to the environment surrounding the pens or leached into the soil. If runoff is captured and returned to agricultural fields these losses must not be considered. In humid environments, in cases where manure is left exposed to rainfall, inventory compilers should consider the use of the upper bounds of the leaching fraction and furthermore to consider the development of a country specific leaching fraction.

Review of the effect of slurry store solid covers and natural crust on emissions of CH_4 and N_2O

The review found 18 papers dealing with the impact of solid covers or natural crusts on CH_4 and/or N_2O emissions from slurry stores. 11 of them were suitable to be included here to deduce emission factors (Amon *et al*. 2006; Clemens *et al*. 2006; Guarino *et al*. 2006; Amon *et al*. 2007; VanderZaag *et al*. 2008; VanderZaag *et al*. 2009; Aguerre *et al*. 2012; Nielsen *et al*. 2013; Hou *et al*. 2015; Matulaitis *et al*. 2015; Misselbrook *et al*. 2016).

For CH_4 emissions from Liquid/Slurry, the *2006 IPCC Guidelines* state that by judgement of the IPCC Expert Group, a reduction of 40 percent due to crust cover may be applied when a thick, dry, crust is present. The new review carried our within the *2019 Refinement* confirms this judgement (VanderZaag *et al*. 2008; Aguerre *et al*. 2012; Nielsen *et al*. 2013). A solid cover reduces CH_4 emissions by 25 to 50 percent (range: 0 to 90 percent) (Amon *et al*. 2006; Clemens *et al*. 2006; Guarino *et al*. 2006; Amon *et al*. 2007; VanderZaag *et al*. 2008; VanderZaag *et al*. 2009; Hou *et al*. 2015; Matulaitis *et al*. 2015; Misselbrook *et al*. 2016).

For N_2O emissions from Liquid/Slurry with natural crust cover a detailed literature review carried out during the *2019 Refinement* revealed only very few new datasets on the measurement of N_2O emissions from manure stores and the influence of crusting. These datasets agree that N_2O emissions increase when a crust is formed, but do not give concrete numbers on the level of increase (VanderZaag *et al*. 2008; Aguerre *et al*. 2012).

For N_2O emissions from Liquid/Slurry with a cover 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 encompass a large range from a 50 percent reduction to a 100 percent increase in N_2O emissions when slurry stores are covered. The *2019 Refinement* therefore suggest to use the emission factor of crust cover (Amon *et al*. 2006; Clemens *et al*. 2006; Guarino *et al*. 2006; Amon *et al*. 2007; VanderZaag *et al*. 2009; Hou *et al*. 2015; Misselbrook *et al*. 2016).

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Annex 10A.1 Data underlying methane default emission factors for Enteric Fermentation, Volatile solids and nitrogen excretion and retention fractions for Cattle and Buffalo

(see References in Annex 10B.1)

Annex 10A.2 Additional data and information for the calculation of methane and nitrous oxide from Manure Management

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Annex 10A.3 MCF Spreadsheet example for the calculation of a country or regions specific MCF

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Annex 10.B Data and Explanatory Text for Development of New Parameters in the *2019 Refinement*

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10B.2 Estimation of Cattle/Buffalo CH_4 conversion factors (Y_m)

(References in Section 10.3 Methane Emissions from Enteric Fermentation)

10B.3 Estimation of Default Emission Factor(s) for Goat Tier 2 parameters

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10B.5 Basis for Changes to MCF Calculations for Liquid/Slurry

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