# $CH_4$ AND $N_2O$ EMISSIONS FROM LIVESTOCK MANURE


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## ABSTRACT

Livestock are produced throughout the world and are a significant contributor to global methane ($CH_4$) emissions. Methane, a greenhouse gas, is produced from the decomposition of livestock manure under anaerobic conditions. These conditions often occur when large numbers of animals are managed in a confined area (e.g., dairy farms, beef feedlots, and swine and poultry farms) where manure is typically stored in large piles or disposed of in lagoons. Nitrous oxide, also a greenhouse gas, is produced during the nitrification-denitrification of nitrogen contained in livestock waste.

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*IPCC Guidelines*) provide a general guide to estimating methane emissions from livestock manure. Two approaches may be used to estimate emissions: the Tier 1 approach relies on default emission factors drawn from previous studies, while the more complex Tier 2 approach requires country-specific information on livestock manure characteristics and manure management practices. The Tier 2 approach is recommended when the data used to develop the default values does not correspond well with the country's livestock and manure management conditions or when a country has large dairy and swine populations.

To prepare methane estimates, livestock population data characterized by subgroup are required. For Tier 1 estimates, necessary population data should be readily obtainable within the country or from the Food and Agricultural Organization (FAO). The Tier 2 estimates require additional data on manure characteristics and manure management practices, for which country-specific data should be used. These data should be obtained through data collection activities. If necessary, IPCC default values can be used for some of the factors in the Tier 2 calculation.

Nitrous oxide estimates also require livestock population and manure management practice data. The value and source of these data should correspond with that used for estimating methane emissions.

Reporting of emission estimates for both methane and nitrous oxide is clearly described in the *IPCC Guidelines.* With few exceptions, confidentiality is not expected to pose a challenge.

Ensuring the quality of the inventory will be an important activity, particularly where Tier 2 methods are used. The most important aspect of QA/QC (quality assurance/quality control) is thorough and transparent documentation of the emissions calculation steps, including all activity data and emission factor values.

# 1 INTRODUCTION

## 1.1 Nature, magnitude, and distribution of source

### 1.1.1 Overview

***Methane Generation***

The principal factors affecting methane emission from livestock manure are the amount of manure that is produced and the portion of the manure that decomposes anaerobically. The total amount of manure produced can be estimated using an average amount of manure produced per animal and the number of animals. The type of manure management system used and the climate (primarily temperature) are the primary factors that determine the extent of anaerobic decomposition that takes place.

Some livestock producers reduce the amount of methane that escapes into the atmosphere by constructing lids or caps for lagoons or tanks where manure is kept. This recovered methane is often flared or used as a fuel in a boiler, heater, or an engine-generator.

***Nitrous Oxide Generation***

Production of $N_2O$ during storage and treatment of animal wastes can occur via combined nitrification-denitrification of nitrogen contained in the wastes. The amount of $N_2O$ released depends on the system and duration of waste management. Because $N_2O$ production requires an initial aerobic reaction and then an anaerobic process, it is theorized that dry, aerobic management systems may provide an environment more conducive for $N_2O$ production.

### 1.1.2 Process description

***Methane***

Livestock manure is primarily composed of organic material and water. Under anaerobic conditions, the organic material is decomposed by anaerobic and facultative bacteria. The end products of anaerobic decomposition are methane, carbon dioxide, and stabilized organic material. The methane production potential of manure depends on the specific composition of the manure, which in turn depends on the composition and digestibility of the animal diet.

The amount of methane produced during decomposition is influenced by the climate and the manner in which the manure is managed. The management system determines key factors that affect methane production, including contact with oxygen, water content, pH levels, and nutrient availability. Climate factors include temperature and rainfall. Optimal conditions for methane production include an anaerobic, water-based environment, a high level of nutrients for bacterial growth, a neutral pH (close to 7.0 ), and warm temperatures.

The key factors affecting methane production from livestock manure are the quantity of manure produced, manure characteristics, the manure management system, and climate.

**Quantity of Manure Production**

Manure production varies by animal type and is proportional to the animal's weight and feed intake.

**Manure Characteristics**

The portion of manure that can generate methane is the volatile solids portion (VS)[1]. The VS portion depends on livestock type and diet, which also affect the quantity of methane that can be produced per kilogram of volatile solids (VS) in the manure.

**Manure Management System**

Methane production depends on the type of manure management system, which can be broadly divided into "liquid" and "dry" systems. Dry systems include solid storage, dry feedlots, deep pit stacks, and daily spreading of the manure. In addition, unmanaged manure from animals grazing on pasture falls into this category. Liquid

[1] Volatile solids (VS) are the organic fraction of total solids in manure that will oxidize and be driven off as gas at a temperature of 600$^{o}$C.

management systems often use water to facilitate manure handling. These systems include tanks and lagoons which store manure until it is applied to cropland. Liquid systems create the ideal anaerobic environment for methane production. Detailed descriptions of these systems are provided in Table 10 in Annex 2.

**Climate**

Manure decomposes more rapidly when the climate encourages bacterial growth. For liquid manure systems, warm temperatures increase methane generation. For solid systems, rainfall can affect methane production, with wet climates having higher emissions than arid climates. In either case, emissions from solid systems tend to be very low.

***Nitrous Oxide***

Nitrous oxide is produced from the combined nitrification-denitrification process that occurs on the nitrogen in manure. The majority of nitrogen in manure is in ammonia ($NH_3$) form. Nitrification occurs aerobically and converts this ammonia into nitrate, while denitrification occurs anaerobically, and converts the nitrate to $N_2O$. Temperature, pH, biochemical oxygen demand (BOD), and nitrogen concentration affect $N_2O$ generation. BOD is the amount of dissolved oxygen used by aerobic microorganisms to completely consume the available organic matter.

Increasing aeration initiates the nitrification-denitrification reactions, and hence makes release of $N_2O$ possible. Therefore, as fresh dung and slurry is highly anoxic and well-buffered with near neutral pH, $N_2O$ production is expected to increase with increasing aeration. However, the denitrification process that produces $N_2O$ requires an anaerobic environment. Currently, there is not enough quantitative data to derive a relationship between the degree of aeration and $N_2O$ emissions. This makes $N_2O$ emissions estimates from this source highly uncertain.

# 2 METHODOLOGICAL ISSUES

## 2.1 Selection of good practice methods

The *IPCC Guidelines* provides a general approach to estimate methane emissions from livestock. The three main steps used to estimate methane emissions from livestock manure are as follows: a) collect activity data for livestock population groups and subgroups; b) estimate emissions factors for each subgroup or use default emission factors; and c) multiply the emission factor by the population to obtain total methane emission estimate for the population. The total emissions estimates should be reported in gigagrams (Gg). Because the emission factors are reported in kilograms per head per year, the total emissions in Gg is estimated as follows:

$$\text{Emission Factor (kg/head/yr)} \bullet \text{Population (head)} / (10^6 \text{ kg/Gg}) = \text{Emissions Gg/yr.}$$

To execute this process in the most efficient manner, the *IPCC Guidelines* recommends two approaches to estimate methane emissions from livestock manure.

The **Tier 1** approach 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.

The **Tier2** approach provides a more detailed method for estimating methane emissions from manure management systems. This approach is recommended for countries with large livestock populations managed under confined conditions because the Tier 1 method will not accurately account for the higher level of emissions that are generally produced in confined facilities. This method requires detailed information on animal characteristics and the manner in which manure is managed. Using this additional information, emission factors specific to the conditions of the country are estimated and the default emission factors from Tier 1 are not used.

Countries are encouraged to carry out emissions inventory calculations at a finer level of detail beyond Tier 2 if possible. This can include conducting regional analyses of emissions to account for differences in livestock and manure characteristics, climate, and manure management practices across specified regions.

For $N_2O$, the *IPCC Guidelines* recommends an approach similar to the Tier 2 methane approach. Information on how manure is managed is used to identify default emission factors. These are used with nitrogen excretion estimates for each livestock group based on animal population data to estimate $N_2O$ emissions.

$N_2O$ emissions from all waste management systems are reported under this emissions source category with three exceptions:

- Manure that is applied to agricultural soils (e.g., daily spread);
- Manure deposited by grazing animals on fields (pasture range and paddock), and

- Manure used for fuel.

$N_2O$ emissions from manure that is managed in these systems are instead accounted for in the methodology for estimating direct emissions from agricultural soils, direct soil emissions of $N_2O$ from animal production, and manure used as fuel, respectively. The class "used for fuel" is not included here as a source of $N_2O$ because it is considered an energy-related emission. Currently, this class incorrectly includes manure managed in anaerobic digesters.

## 2.2 Emissions factors

### *Methane*

Emission factors are estimates of methane produced in kilograms per animal. Emission factors help to standardize emissions across many different livestock groups so that relatively correct total emission estimates can be made.

**Tier 1** In this step, emission factors that are most appropriate for the country's livestock characteristics are selected. The *IPCC Guidelines* include default emission factors, which have been drawn from previous studies and are organized by region (Tables 4.5 and 4.6 from the *IPCC Guidelines* are included in Annex 1).

The Tier 1 emission factors incorporate assumptions about manure composition, climate, and manure system usage for developed and developing countries, as described in the Tier 2 discussion below.

The climate data collected as part of the activity data is used to select the appropriate emission factors. If a country manages livestock in more than one climate zone, a weighted average emission factor for each animal type should be computed by multiplying the percentages of the animal populations in each climate region by the emission factor for each climate region.

Weighted Emission Factor = Percentage of Animal Population in Climate • Climate Emission Factor

**Tier 2** The Tier 2 emission factors are calculated based on country-specific data on manure composition, manure methane producing capacity, climate, and waste system usage. The major components of the emission factor calculation are as follows:

- *Volatile Solids (VS)* is the portion of the manure that produces methane. Often, data on average daily VS excretion are not available. Therefore, the VS values may need to be estimated from feed intake levels and characteristics. Feed intake data for cattle should be determined by selecting a representative animal from each animal type. The IPCC’s suggested methodology for estimating VS using feed data is shown in Annex 2, which reprints Equation 15 from the *IPCC Guidelines.*

- *Methane Producing Potential ($B_O$)* is the maximum amount of methane that can be produced from a given quantity of manure. The methane producing potential varies by animal type and diet. The *IPCC Guidelines* provide default values for each major global region. The values determined for US livestock are used for all of the developed country regions, and a slightly modified value is used for some categories in the developing country regions. Using country-specific $B_O$ factors based on recent measurement data or research should improve the reliability of the resulting emissions factor.

- *Methane Conversion Factor (MCF)* defines the portion of the methane producing potential ($B_O$) that is achieved. The MCF varies with the manner in which the manure is managed and the climate, and can theoretically range from 0 to 100 percent. Manure managed as a liquid under warm conditions has a high MCF of 65 to 90 percent. Manure managed as dry material in cold climates has a low MCF at 1 percent. Default MCFs by manure system have been developed from previous studies; the IPCC’s recommended MCF’s are shown in Annex 2, in Table 11, which was taken from the *IPCC Guidelines.* Incorporating additional research on methane production under various management scenarios may improve the accuracy of these factors.

- *Fraction of Manure in Management System (MS%)* describes the portion of each livestock group's manure that is handled by a specific manure management technique. This factor is collected as activity data, discussed in Section 2.3.

These four variables are used in the equation to calculate emission factors as follows:

**EQUATION 1**

$$EF_i = VS_i \bullet 365 \text{ days/yr} \bullet B_{oi} \bullet 0.67 \text{ kg/m}^3 \bullet \sum_{jk} MCF_{jk} \bullet MS\%_{ijk}$$

Where:

$EF_i$: annual emission factor (kg) for animal type i (e.g., dairy cows);

$VS_i$: daily VS excreted (kg) for animal type i;

$B_{oi}$: maximum methane producing capacity ($m^3$/kg of VS) for manure produced by animal type i;

$MCF_{jk}$: methane conversion factors for each manure management system j by climate region k; and

$MS\%_{ijk}$: fraction of animal type i's manure handled using manure system j in climate region k.

***Nitrous Oxide***

Nitrous oxide emission factors are estimates of kilogram of nitrous oxide nitrogen produced per kilogram of nitrogen excreted. These factors vary by waste management system, as shown in Table 1

**TABLE 1**

**TENTATIVE DEFAULT VALUES FOR $N_2O$ EMISSION FACTORS FROM ANIMAL WASTE PER ANIMAL WASTE MANAGEMENT SYSTEM (KG $N_2O$ - N/KG NITROGEN EXCRETED)**

| Animal Waste Management System | Emission Factor EF |
|---|---|
| Anaerobic lagoons | 0.001 (<0.002) |
| Liquid systems | 0.001 (<0.001) |
| Daily spread[a] | 0.0 (no range) |
| Solid storage and drylot[a] | 0.02 (0.005-0.03) |
| Pasture range and paddock (grazing)[b] | 0.02 (0.005-0.03) |
| Used as fuel[c] | Not Applicable |
| Other systems[b] | 0.005 |

[a] Considered to be a part of direct soil emissions from agricultural fields after spreading.

[b] Considered to be a part of direct soil emissions from animal production.

[c] Considered to be a part of emissions from energy.

Source: IPCC, 1996.

## 2.3 Activity data

Activity data include data on livestock population, and manure management system usage. The Tier 1 methodology for methane emissions requires data on livestock population by livestock group. Both the Tier 2 methodology for methane and the nitrous oxide methodology require livestock population data and data on manure system usage.

**Methane**

**Tier 1:** The *IPCC Guidelines* recommend collecting the average annual population of livestock listed in Table 2. It is recommended that countries collect their own population data. The number of animals recorded depends on the time at which the census is taken. For example, a census taken before most calves are born yields a lower number of animals than a census taken after most calves are born. Data should represent an average estimate for the entire year. If population data cannot be collected, it can be obtained from an outside source such as the Food and Agriculture Organization (FAO) or similar country-specific livestock census reports.

| TABLE 2<br>DOMESTIC LIVESTOCK INCLUDED IN THE TIER 1 METHODOLOGY |
|---|
| **Livestock** |
| Dairy Cattle |
| Non-Dairy Cattle |
| Buffalo |
| Sheep |
| Goats |
| Camels |
| Horses |
| Mules and Asses |
| Swine |
| Poultry |

As shown in Table 2, IPCC recommends recording data on dairy cattle separate from other cattle. Dairy cattle are defined as mature cows producing milk in commercial quantities for human consumption, and are managed differently from non-dairy cattle. This generally results in differences in composition and methane production potential between dairy and non-dairy cattle manure. Additionally, dairy cattle manure is often managed differently from cattle manure.

In some countries, there are two types of dairy cows: high-producing, “improved” breeds in commercial operations and low-producing breeds managed with traditional methods. If possible, countries can separate the dairy cow population into two groups. The dairy cow group does not include cows used mainly for producing calves or for draft power. These cows are accounted for in non-dairy cattle data.

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

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

The fraction of each livestock population should be estimated for each climate. This data can be developed from country-specific climate maps and livestock census reports. To the extent possible, the temperature data should reflect the locations where the livestock are managed.

**Tier 2:** In addition to the livestock population data described for Tier 1, the Tier 2 approach also requires data on the percentage of manure managed with each management system. Data should be collected for each management system. Table 12 in Annex 2 summarizes the main types of manure management systems, which can be broadly divided into "wet" and "dry" systems. If specific management system data does not exist, there should be at least a division of manure production into wet and dry systems. The IPCC provides default manure management practice data for major regions based on Safley, et al. (1992). If country-specific data exists or can be collected, it should be used. Additionally, if the current data predates known changes in manure management practices, they should be updated to reflect the current practices.

**Nitrous Oxide**

In addition to livestock population and manure management system data (described above), the nitrous oxide emissions estimation approach also requires nitrogen excretion data by animal type. It is recommended that country-specific data be collected and used. This may require manure composition analysis, which should be coordinated with any research to determine volatile solids content. If this is not feasible, regional default values can be used. These are provided in Table 3.

**TABLE 3**

**TENTATIVE DEFAULT VALUES FOR NITROGEN EXCRETION PER HEAD OF ANIMAL PER REGION (KG/ANIMAL/YR)**

| **Region** | **Type of Animal** | | | | | |
|---|---|---|---|---|---|---|
| | Non-Dairy Cattle | Dairy Cattle | Poultry | Sheep | Swine | Other Animals |
| North America | 70 | 100 | 0.6 | 16 | 20 | 25 |
| Western Europe | 70 | 100 | 0.6 | 20 | 20 | 25 |
| Eastern Europe | 50 | 70 | 0.6 | 16 | 20 | 25 |
| Oceania | 60 | 80 | 0.6 | 20 | 16 | 25 |
| Latin America | 40 | 70 | 0.6 | 12 | 16 | 40 |
| Africa | 40 | 60 | 0.6 | 12 | 16 | 40 |
| Near East & Mediterranean | 50 | 70 | 0.6 | 12 | 16 | 40 |
| Asia & Far East | 40 | 60 | 0.6 | 12 | 16 | 40 |

Source: IPCC, 1996.

## 2.4 Uncertainty

Parallel to the IPCC sector-specific meetings on good practice guidance, the IPCC is completing a programme of work on emissions inventory uncertainty. This work will result in recommendations to the United Nations Framework Convention on Climate Change (UNFCCC) on approaches to assessing and managing uncertainty. During the IPCC Inventory Experts Group Meeting in Paris (October 1998), technical experts in the uncertainty programme came up with a series of questions to be answered in the sector meetings. Specifically, the sector meetings should provide answers to these questions in the individual source context. The questions are listed in the general background paper.

**Methane**

**Tier 1:** Given that the emissions factors for Tier 1 are not based on country-specific data, they do not represent accurately the manure management system characteristics for any given country. The emissions factors are highly uncertain as a result. Emission factors should be updated for regions that have experienced significant changes in manure management practices.

**Tier 2:** One source of uncertainty in the Tier 2 emissions factors is the manure system usage data. The level of confidence in this data depends on the methods used to collect the data for each country. Additionally, there is uncertainty in the MCFs used to estimate the portion of the methane production potential that is realized in each manure management system. Conditions can vary significantly, particularly in liquid systems. The default MCFs may not account for all of the variability in methane production that can exist within systems. A secondary source of uncertainty lies in the equations used to calculate the emissions factor (presented in Annex 2). Generally, uncertainty in the equations is low compared to the uncertainty in the manure system usage data. Consequently, efforts undertaken to reduce uncertainty should focus first on improving this data.

**Nitrous Oxide**

In addition to the uncertainty in the manure system usage data, there is also uncertainty in the nitrogen excretion data. Similar to manure system usage, the level of uncertainty in nitrogen excretion data depends on the methods used to collect the data. As discussed before, there is also a high level of uncertainty in the emission factors that arises from a lack of data on $N_2O$ production from manure.

## 2.5 Completeness

Given that the different livestock species are distinct and population data are generally available, each country is expected to create a complete inventory comprised of emissions estimates for each required livestock species. If population data are unavailable, countries can use data collected by FAO (FAO, 1999).

# 2.6 Other important issues

## 2.6.1 Baseline

An emission baseline is an important component of an inventory programme. Below is a description of issues related to creating a baseline for the methane and nitrous oxide methods recommended by the IPCC.

**Methane**

**Tier 1:** Developing a baseline for Tier 1 requires collecting and compiling animal population data during the baseline period. For the Tier 1 methodology, difficulties arise when

- Animal population data are not available for the baseline period;
- Animal population data during the baseline period are not broken down into the animal groups recommended by IPCC, and
- Changes in manure management practices over time affect methane emissions.

Approaches to overcoming these difficulties include collecting aggregate historical data from FAO and using current data to break out historical population data into the animal groups. If changes in manure management practices affect methane emissions significantly, the Tier 1 method is unreliable, and the Tier 2 method should be used.

**Tier 2:** Developing a baseline for Tier 2 requires the collection and compilation of manure management system usage data during or following the baseline period. In addition to the issues related to animal population data described for Tier 1, difficulties arise in the Tier 2 methodology when:

- Manure management system data are not available for the baseline period;
- Manure management system data during the baseline period are not broken down into the systems recommended by IPCC, and
- The Tier 2 methodology was not used throughout the baseline period.

Approaches to overcoming a lack of substantial management system data include applying a sample area or region's manure management practice trends to the entire country. If emission estimation methodologies have changed, historical data that are required by the current methodology should be collected and used to re-estimate emissions for that period. If these data do not exist, it may be appropriate to create a trend with recent data and use the trend to back-estimate management practices for the baseline period. Among other sources, publications, industry and university experts can be used to estimate trends for the livestock and feed characteristics.

**Nitrous Oxide**

The issues related to animal population and manure management practices described for methane also apply to emissions from nitrous oxide.

## 2.6.2 Accurate detection of mitigation measures

Efforts to reduce methane emissions through improved productivity, and thus declining livestock populations, would be reflected in the livestock population data. This decline would directly affect manure and volatile solids production, as well as nitrogen production. All other factors kept constant, decreases in volatile solids and nitrogen production would reduce methane and nitrous oxide emissions.

Shifts in manure management practices towards dry systems would have a similar affect on methane emissions. On a weight basis, manure in dry systems produces significantly less methane than liquid systems. Even with increased manure production, shifts toward dry systems could decrease methane emissions dramatically. Based on default emission factors, such shifts would presumably have an opposite effect on nitrous oxide emissions. However, the high uncertainty associated with these factors may diminish any effects of such changes.

The current methodology accounts for manure handled in anaerobic digesters. The IPCC default MCF for these digesters is 5-15%, which is much lower than the MCF values for anaerobic lagoons (90%) and liquid/slurry systems (10-65%). Thus, increased handling of manure in such systems could significantly decrease methane emissions.

### 2.6.3 Consistency with inventory for livestock digestive systems

The livestock characterization used to estimate methane and nitrous oxide emissions from livestock manure should be consistent with the characterization used for methane emissions from livestock digestive systems. If there are conflicts or inconsistencies, these should be resolved as soon as possible.

# 3 REPORTING AND DOCUMENTATION

A recent report from the UNFCCC Secretariat "Methodological Issues Identified While Processing Second National Communications" (UNFCCC/SBSTA/1998/7) noted that almost all countries reported methane emissions from manure, and all countries, with the exception of two countries, reported emissions from manure separately from enteric fermentation emissions. Specifically, Belgium included emissions from manure with emissions from enteric fermentation and Estonia reported methane emissions from all agriculture rather than separating each agricultural source (Estonia, 1998).

In reporting emissions, countries should include all activity data, and document the source of the data. Countries using the methane Tier 2 approach should also explicitly show the emission factor calculation method. This includes the calculation method and steps to determine the respective emission factors that are weighted and aggregated across manure management systems to produce a single factor for each livestock category.

## 3.1 Current IPCC reporting guidelines

The *IPCC Guidelines* are used to guide countries in the preparation and submissions of annual greenhouse gas emissions inventories to the UNFCCC Secretariat. The Guidelines establish:

- Standard tables, definitions, units, and time intervals for reporting all types of emissions;
- Necessary documentation to enable comparison of national inventories, including worksheets, major assumptions, methodological descriptions, and enough data to allow a third party to reconstruct the inventory from national activity data and assumptions, and
- An uncertainty assessment.

Both methane and nitrous oxide emissions from livestock manure are reported in Table 4, Volume 2 of the *IPCC Guidelines* - Sectoral Report for Agriculture. This table requires recording emissions from each livestock source, and also across the major manure management systems.

## 3.2 Confidential business information

In isolated cases, reporting population data and information on management practices may be a problem in regions with a small number of large, commercial operations. Confidentiality is not expected to be a significant issue for this source.

# 4 INVENTORY QUALITY

## 4.1 Introduction

Inventory quality assurance and quality control (QA/QC) is a process integral to the development of a credible inventory. A well-developed and well-implemented quality assurance programme fosters confidence in the final inventory results regardless of the purpose and goal of the inventory. A successful quality assurance programme requires internal quality control procedures and an unbiased, external review and audit. The internal QC activities are designed to ensure accuracy, documentation, and transparency. The external review process is designed to minimize errors that occur in the preparation of emissions inventories, and reduce or eliminate potential inherent bias. Figure 1 outlines the flow of information and processes followed at each step.

**Figure 1 Inventory QA/QC Process**

**Data Collection Agency**

**Internal QC:** Activity data, emissions factors, and calculations

**Documentation:** Production data provided to the government agency, and results of internal QC

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**Government Agency**

**Review/QA:** Activity Data, emissions factors, and calculations

**Internal QC:** Compilation of national inventory from activity data

**Documentation:** Results of compilation and results of QA/QC

**Reporting:** Official submission to UNFCCC

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**External Review**

**External Review:** External audit, stakeholders, peer and public review of inventory results, external verification against other data etc.

**Documentation:** Results of external review

⇩

**UNFCCC Secretariat**

**External Review:** Requires standard format and transparency – ensure consistency with other inventories and external data

# 4.2 Internal inventory QA/QC systems

## 4.2.1 Emissions factors

### Emissions Factors QC

#### *Methane*

**Tier 1:** The emissions factors are based on default data. QC procedures include reviewing the available default values and documenting the rationale for selecting specific values. Other QC procedures are not required.

**Tier 2:** QC procedures for the Tier 2 emissions factors involve checking the equations and calculations used to calculate the emissions factor. The Tier 2 emissions factors are based on country-specific information on animal and feed characteristics. QC procedures on these data are described below in the Activity Data section.

#### *Nitrous Oxide*

The emissions factors are based on default data. QC procedures include reviewing the available default values and documenting the rationale for selecting specific values. Other QC procedures are not required.

#### *Emissions Factors Documentation*

Documentation is a crucial component of the review process because it enables reviewers to identify mistakes and suggest improvements. Among other elements, a detailed description of the equations used to estimate emissions factors is needed. In addition, a standardized reporting form is recommended to provide transparent information on the steps taken to calculate the emissions factors. Each step should contain the numbers used in each calculation, including the source of any data collected.

## 4.2.2 Activity data

#### *Activity Data QC*

**Tier 1 and Tier 2 *Livestock Population Data:*** The annual livestock population data are generally collected by a country's ministry of agriculture or a similar organization focused on the agriculture sector. The personnel that collect data are responsible for reviewing the data collection methods, checking the data to ensure they were collected and aggregated correctly, and cross-checking the data with previous years to ensure the data are reasonable. The basis for the estimates, whether statistical surveys or "desk estimates," must be reviewed and described as part of the QC effort.

**Tier 2 *Manure Management Practices Data:*** There are generally two approaches to collecting manure management system usage data: a) a government agency or related body collects the data by surveying farms; or b) the agency or related body interviews industry and university experts. The QC activities for the two approaches are described below:

- *Farm Survey*: Government agencies, such as the ministry of agriculture or a related body, collect the animal and feed characteristics data required for the inventory. The personnel collecting the data are responsible for reviewing the collection methods, checking to ensure the data were collected and aggregated correctly, and comparing data with data from previous years to ensure the data are reasonable.

- *Industry and University Experts*: Manure system usage data may be obtained by surveying and interviewing industry and university experts. The personnel collecting the data are responsible for reviewing surveys used to collect the data to make sure the survey is appropriate for the data needs. Questions used in interviews should also be reviewed.

#### *Activity Data Documentation*

Documentation is a crucial component of the review process, because it enables reviewers to identify mistakes and suggest improvements. Among other information, the following is needed for the reviewing/auditing agency:

- A highly detailed description of the methods used to collect the activity data, and

- A discussion of potential areas of bias in the data, including a discussion of whether the manure management practices are representative of the country.

## 4.2.3 Inventory agency level activities

**Inventory Agency Review of Activity Data QA**

Before accepting the activity data, the inventory agency should assess them, including all data on the animal population and manure management practices. This review involves close cooperation with the personnel responsible for collecting, compiling, and analyzing the data. The assessment should include a review of the detailed methods used to collect the data, including a review of any surveys and interviews performed to collect the data. In addition, the assessment should include a comparison of the activity data with historical data, a discussion of the potential for bias, and recommendations for improvement.

**Inventory Agency QC on Compiling National Emissions**

In addition to a thorough quality assessment of data discussed above, the inventory agency should ensure that the process of aggregating data to develop the national inventory undergoes quality control. This should include, among other things:

- Cross-referencing the aggregated population data with the national totals;

- Back-calculating national and regional emissions factors from the Tier 2 management system usage data (if using Tier 2);

- Ensuring that the manure management practices are representative of the country (if using Tier 2);

- Ensuring that all farms are included in the population data, and

- Comparing with national trends to look for anomalies.

**Inventory Agency Documentation on Compiling National Emissions**

For the $CH_4$ emission inventory for enteric fermentation, a QA/QC management plan should address the specific items needed to perform audits and reviews. Examples of the types of information needed for documentation and external audit include:

- A detailed description of the inventory methodology;

- Identification of the input parameters that are needed and how the input parameters are obtained, and

- Frequency of data collection and estimation and results of determinations of accuracy and precision.

## 4.3 External inventory QA/QC systems

External QA activities include a planned system of review and audit procedures conducted by personnel not actively involved in the inventory development process. The key concept is an independent, objective review to assess the effectiveness of the internal QC programme, the quality of the inventory, and to reduce or eliminate any inherent bias in the inventory processes. Several types of external reviews, or audits, may be appropriate for the inventory of $CH_4$ and $N_2O$ emissions from livestock manure.

- **Third party audit by an accredited organization, expert, independent third party:** An audit of the documentation and calculations ensures that each number is traceable to its origin.
- **Expert (peer) review:** Although a detailed peer review would be appropriate when a procedure for determining $CH_4$ emissions is first adopted or revised; it would not be needed on an annual basis. Such a review is designed to ensure that the methodology is rigorous, accurate, and that the data and assumptions reflect the best available information.
- **Stakeholder review:** Review by industrial organizations and government can provide a forum for review of the methods used.
- **Public review:** Some countries make their entire inventory available for public review and comment. This process may result in a range of comments and issues broader than those from other review processes.

**Confidential Business Information Issues**

Confidentiality is not a major issue when private parties review the data. However, in areas with several large, commercial producers, there may be opposition to releasing the activity data to the public.

# 5 UPDATES TO ESTIMATION METHODS

At the IPCC workshop on Good Practices in Inventory Methods held in the Netherlands on February 24-26, 1999, participants recommended updates to the Tier 2 method used to estimate methane emissions from livestock manure. These updates included the following:

- Modifications to the maximum methane producing capacity of cattle, poultry, and swine based on recent research;
- New MCF values for liquid/slurry and pit storage manure management systems;
- Revised definitions for several management systems, and
- The addition of new manure management systems into the IPCC list of systems.

Recent work by Zeeman and Gerbens (1999) showed that $B_o$ values for swine manure may be lower than the IPCC default value. The latter would suggest an unrealistic high biodegradability of 92% (Zeeman and Gerbens, 1999), in contradiction to the observed biodegradability of 70% (Zeeman, 1994). Therefore it is proposed that the estimated $B_o$ (Zeeman and Gerbens, 1999) values should be used as the default values in the *IPCC Guidelines*. A comparison of these values is shown in Table 4.

**TABLE 4**

**RANGE IN $B_O$ VALUES REPORTED BY SAFLEY ET AL.(1992) AND ESTIMATED $B_O$ VALUES FOR DEVELOPED AND DEVELOPING COUNTRIES (ZEEMAN AND GERBENS,1999) IN COMPARISON TO IPCC DEFAULT VALUES ($M^3$ $CH_4$/KG VS)**

| | IPCC (1996) Developed Countries | IPCC (1996) Developing Countries | Safley et al. (1992) | Zeeman and Gerbens (1999) Developed | Zeeman and Gerbens (1999) Developing |
|---|---|---|---|---|---|
| | Default | Default | range | estimated | estimated |
| Non-dairy | 0.17 | 0.10 | 0.17-0.33 | | |
| Dairy | 0.24 | 0.13 | 0.10-0.24 | 0.25 | 0.14[1] |
| Poultry | 0.32 | 0.24 | 0.24-0.39 | | |
| Swine | 0.45 | 0.29 | 0.32-0.52 | 0.34 | 0.22[1] |

Estimated $B_o$ values for developing countries (Zeeman and Gerbens, 1999) are proportionally lower and similar to the IPCC estimate for $B_o$ values for developinged regions.

The participants also proposed using revised MCF values based on values observed by Zeeman(1994) shown in Table 5.

**TABLE 5**

**COMPARISON BETWEEN IPCC DEFAULT MCF VALUES AND PROPOSED MCF VALUES**

| Manure management Strategy | Climatic condition | MCF (%) (IPCC, 1995) | MCF (%) (Zeeman and Gerbens, 1999) |
|---|---|---|---|
| Liquid/slurry | Cool | 10 | 39 |
| | Temperate | 35 | 45 |
| | Warm | 65 | 72 |
| Pit < 1 month | Cool | 5 | 0 |
| | Temperate<br>warm | 18<br>33 | 0<br>30 |
| Pit > 1 month | Cool | 10 | 39 |
| | Temperate | 35 | 45 |
| | Warm | 65 | 72 |

In addition, it was recommended that digesters and anaerobic lagoons be subdivided to account for recovery, flaring and use of the biogas including the gas produced/emitted during manure storage after digestion. The proposed revisions to the manure management system definitions and MCF values are shown in Table 6. The proposed additional management systems are shown in Table 7.

**TABLE 6**

**MANURE MANAGEMENT SYSTEMS (BLANK MEANS NO CHANGE FROM CURRENT IPCC DEFINITIONS/MCFS)**

| System | Definition | MCFs by Climate | | | Comments |
|---|---|---|---|---|---|
| | | Cool | Temperate | Warm | |
| Pasture/Range/ Paddock | | | | | |
| DailySpread | Dung and urine is collected by some means such as scraping. The collected waste is applied to fields. | | | | |
| Solid Storage | Dung and urine are excreted in a stall. The solids (with or without litter) are collected and stored in bulk for a long time (months) before disposal, with or without liquid runoff into a pit system. | | | | |
| Drylot | | | | | |
| Liquid/Slurry | Dung and urine are collected and transported in liquid state to tanks for storage. Liquid may be stored for a long time (months). To facilitate handling water maybe added. | 39% | 45% | 72% | When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to formula 1. |
| Anaerobic Lagoon | | 0-100% | 0-100% | 0-100% | Should be subdivided in different categories, considering percentage recovery of the biogas and flaring of the biogas. |
| Pit Storage Below Animal Confinements | Combined storage of dung and urine below animal confinements<br><1 month<br>>1 month | 0-39% | 0-45% | 30%-72% | When pits are used as fed-batch storage/digesters, MCF should be calculated according to formula 1. The stable temperature, not the ambient temperature, is to be used for determining the climatic conditions. |

| TABLE 6 (CONTINUED)<br>MANURE MANAGEMENT SYSTEMS (BLANK MEANS NO CHANGE FROM CURRENT IPCC DEFINITIONS/MCFS) | | | | | |
|---|---|---|---|---|---|
| **System** | **Definition** | **MCFs by Climate** | | | **Comments** |
| | | **Cool** | **Temperate** | **Warm** | |
| Drylot | | | | | |
| Anaerobic Digester | The dung and urine in liquid/slurry is collected and anaerobically digested. Methane may be burned flared or vented. | 0-100% | 0-100% | 0-100% | Should be subdivided in different categories, considering amount of recovery of the biogas, flaring of the biogas and storage after digestion . |
| Burned for Fuel | The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel. | | | | |

| TABLE 7<br>PROPOSED NEW MANURE MANAGEMENT SYSTEMS | | | | | |
|---|---|---|---|---|---|
| **Recommended Additional Systems** | **Definition** | **MCFs by Climate** | | | **Comments** |
| | | **Cool** | **Temperate** | **Warm** | |
| Cattle Deep Litter | Cattle dung and urine is excreted on stall floor. The accumulated waste is removed after a long time. | 10% | 35% | 65% | MCF's are similar to liquid/slurry; temperature dependant. |
| Composting – Intensive | Dung and urine is collected and placed in a vessel or tunnel, there is forced aeration of the waste. | 0.5% | 0.5% | 0.5% | MCF's are less than half of solid storage. Not temperature dependant. |
| Composting – Extensive | Dung and urine collected, stacked and regularly turned for aeration. | 0.5% | 1% | 1.5% | MCF's are slightly less than solid storage. Less temperature dependant. |
| Poultry manure with bedding | Manure is excreted on floor with bedding. Birds walk on waste. | 1.5% | 1.5% | 1.5% | MCF's are similar to solid storage but with generally constant warm temperatures. |
| Poultry manure without bedding | Manure is excreted on floor without bedding. Birds do not walk on waste. | 1.5% | 1.5% | 1.5% | MCF's are similar to dry lot at a warm climate. |
| Aerobic Treatment | Dung and manure is collected as a liquid. The waste undergoes forced aeration, or treated in aerobic pond or wetland systems to provide nitrification and denitrification. | 0.1% | 0.1% | 0.1% | MCF's are near zero. |

# 6 CONCLUSIONS

The key issues for estimating emissions from manure management relate to the actual methodology as well as to the creation of a baseline for methane and nitrous oxide emissions. Major issues concerning the Tier 1 methodology include lack of animal population data by animal groups. Approaches to overcoming this difficulty include collecting aggregate historical data from FAO and using current data to break out historical population data into the animal groups. For the Tier 2 methodology, the key issue is obtaining an accurate representation of manure management systems for any particular additional country. Approaches to overcoming this issue include applying a sample area or region's manure management practice trends to the entire country.

Issues to be addressed when developing a baseline include lack of available data, historic data not having been organized as recommended by IPCC, and changes in manure management practices over time that affect emissions results. The approaches for resolving issues include re-examination of historical data by means of the current methodology, the application of data from a representative region to the entire country as well as the creation of a trend with recent data and back-estimating historic data using this trend.

Updates to the Tier 2 method recommended at the IPCC Workshop in *Good Practices* in Inventory Methods held on February 24-26, 1999 in the Netherlands included the results of recent research such as modifications to the maximum methane producing capacity of livestock ($B_o$ values), new MCF values for liquid slurry and pit storage as well as the revision and incorporation of the additional manure management systems currently being used (i.e. daily spread, solid storage, drylot, and anaerobic lagoon were revised; pit storage is a new system that has been incorporated).

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# ANNEX 1 TIER 1 EMISSION FACTORS

**TABLE 8**

**MANURE MANAGEMENT EMISSION FACTORS (KG PER HEAD PER YR.)**

| | Developed Countries | | | Developing Countries | | |
|---|---|---|---|---|---|---|
| Livestock | Cool | Temp.[a] | Warm | Cool | Temp.[a] | Warm |
| Sheep | 0.19 | 0.28 | 0.37 | 0.10 | 0.16 | 0.21 |
| Goats | 0.12 | 0.18 | 0.23 | 0.11 | 0.17 | 0..22 |
| Camels | 1.6 | 2.4 | 3.2 | 1.3 | 1..9 | 2.6 |
| Horses | 1.4 | 2.1 | 2.8 | 1.1 | 1..6 | 2.2 |
| Mules and Asses | 0.76 | 1.14 | 1.51 | 0.60 | 0.90 | 1.2 |
| Poultry[b] | 0.078 | 0.117 | 0.157 | 0.012 | 0.018 | 0.023 |

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

[a] Temp. = Temperate climate region.

[b] Chickens, ducks, and turkeys.

All estimates are ±20%.

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

Source: IPCC, 1996 (Chapter 4, Table 4.5).

**TABLE 9**

**TIER 1 MANURE MANAGEMENT EMISSION FACTORS FOR CATTLE, SWINE, AND BUFFALO**

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

**TABLE 9 (CONTINUED)**

**TIER 1 MANURE MANAGEMENT EMISSION FACTORS FOR CATTLE, SWINE, AND BUFFALO**

| Regional Characteristics | Livestock Type | Emission Factor by Climate Region (kg/head/yr) | | |
|---|---|---|---|---|
| | | Cool | Temperate | Warm |
| **Latin America**: Almost all livestock manure is managed as a solid on pastures and ranges. Buffalo manure is deposited on pastures and ranges. | Dairy Cattle | 0 | 1 | 2 |
| | Non-dairy Cattle | 1 | 2 | 1 |
| | Swine | 0 | 1 | 2 |
| | Buffalo | 1 | 1 | 2 |
| **Africa**: Almost all livestock manure is managed as a solid on pastures and ranges. | Dairy Cattle | 1 | 1 | 1 |
| | Non-dairy Cattle | 0 | 1 | 1 |
| | Swine | 0 | 1 | 2 |
| | Buffalo | | | |
| **Middle East**: Over two-thirds of cattle manure is deposited on pastures and ranges. About one-third of swine manure is managed in liquid-based systems. Buffalo manure is burned for fuel or managed as a solid. | Dairy Cattle | 1 | 2 | 2 |
| | Non-dairy Cattle | 1 | 1 | 1 |
| | Swine | 1 | 3 | 6 |
| | Buffalo | 4 | 5 | 5 |
| **Asia**: About half of cattle manure is used for fuel with the remainder managed in dry systems. Almost 40% of swine manure is managed as a liquid. Buffalo manure is managed in drylots and deposited in pastures and ranges. | Dairy Cattle | 7 | 16 | 27 |
| | Non-dairy Cattle | 1 | 1 | 2 |
| | Swine | 1 | 4 | 7 |
| | Buffalo | 1 | 2 | 3 |
| **Indian Subcontinent**: About half of cattle and buffalo manure is used for fuel with the remainder managed in dry systems. About one-third of swine manure is managed as a liquid. | Dairy Cattle | 5 | 5 | 6 |
| | Non-dairy Cattle | 2 | 2 | 2 |
| | Swine | 3 | 4 | 6 |
| | Buffalo | 4 | 5 | 5 |

The range of estimates reflects cool to warm climates. Climate regions are defined in terms of annual average temperature as follows: Cool = less than 15° C; Temperate = 15° C to 25° C inclusive; and Warm = greater than 25° C. All climate categories are not necessarily represented within every region. For example, there are no significant warm areas in Eastern or Western Europe.

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

Source: IPCC, 1996 (Chapter 4, Table 4.6).

# ANNEX 2 TIER 2 EMISSION FACTORS

### IPCC VS Excretion Rate Equation (Equation 15 in the IPCC Guidelines)

**EQUATION 15**

$$VS\ (kg\ dm/day) = Intake\ (MJ/day) \bullet (1 kg\ dm / 18.45\ MJ) \bullet (1 - DE\% / 100) \bullet (1 - ASH\% / 100)$$

Where:

VS: VS excretion per day on a dry weight basis;

dm: dry matter;

Intake: the estimated daily average feed intake in MJ/day;

DE%: the digestibility of the feed in percent;

ASH%: the ash content of the manure in percent.

**TABLE 10**

**MANURE MANAGEMENT SYSTEMS AND METHANE CONVERSION FACTORS (MCFS)**

| System | | MCF by Climate | | | Source |
|---|---|---|---|---|---|
| | | Cool | Temperate | Warm | |
| Pasture/Range/Paddock: the manure from pasture and range grazing animals is allowed to lie as is, and is not managed. | | 1% | 1.5% | 2% | b |
| Daily Spread: manure is collected in solid form by some means such as scraping. The collected manure is applied to fields regularly (usually daily). | | 0.1% | 0.5% | 1% | b |
| Solid Storage: manure is collected as in the daily spread system, but is stored in bulk for a long period of time (months) before any disposal. | | 1% | 1.5% | 2% | b |
| Drylot: in dry climates animals may be kept on unpaved feedlots where the manure is allowed to dry until it is periodically removed. Upon removal, the manure may be spread on fields. | | 1% | 1.5% | 5% | b |
| Liquid/Slurry: these systems are characterized by large concrete-lined tanks built into the ground. Manure is stored in the tank for six or more months until it can be applied to fields. To facilitate handling as a liquid, water may be added to the manure. | | 10% | 35% | 65% | b |
| Anaerobic Lagoon: anaerobic lagoon systems are characterized by flush systems that use water to transport manure to lagoons. The manure resided in the lagoon for periods from 30 days to over 200 days. The water from the lagoon may be recycled as flush water or used to irrigate and fertilize fields. | | 90% | 90% | 90% | c |
| Pit Storage: liquid swine manure may be stored in a pit while awaiting final disposal. The length of storage time varies, and for this analysis is divided into two categories: less than one month or greater than one month. | <1 month | 5% | 18% | 33% | b |
| | > 1 month | 10% | 35% | 65% | b |
| Anaerobic Digester: the manure, in liquid or slurry form, is anaerobically digested to produce methane gas for energy. Emissions are from leakage and vary with the type of digester. | | 5-15% | 5-15% | 5-15% | d |
| Burned for Fuel: manure is collected and dried in cakes and burned for heating or cooking. Emissions occur while the manure is stored before it is burned. Methane emissions associated with the combustion of the manure are not considered here. Combustion-related emissions are estimated in the *Traditional Biomass Fuels* Section of the *Energy* chapter. | | 5-10% | 5-10% | 5-10% | e |

a The range of estimates reflects cool to warm climates. Climate regions are defined in terms of annual average temperature as follows: Cool = less than 15° C; Temperate = 15° C to 25° C inclusive; and Warm = greater than 25° C.

b Hashimoto and Steed (1993).

c Safley et al., (1992) and Safley and Westerman (1992).

d Yancun et al. (1985), Stuckey (1984) and Lichtman (1983).

e Safely et al., (1992).

Source: IPCC, 1996.