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4.1 LIVESTOCK POPULATION CHARACTERISATION

4.1.1 Methodological issues

The methods for estimating methane (CH_4) and nitrous oxide (N_2O) emissions from livestock-related source categories all require information such as the definitions of livestock sub-categories, annual populations and feed intake estimates. To ensure that these definitions and data are used consistently across the source categories a single ‘characterisation’ should be developed for each species. A coordinated livestock characterisation ensures consistency across the following source categories:

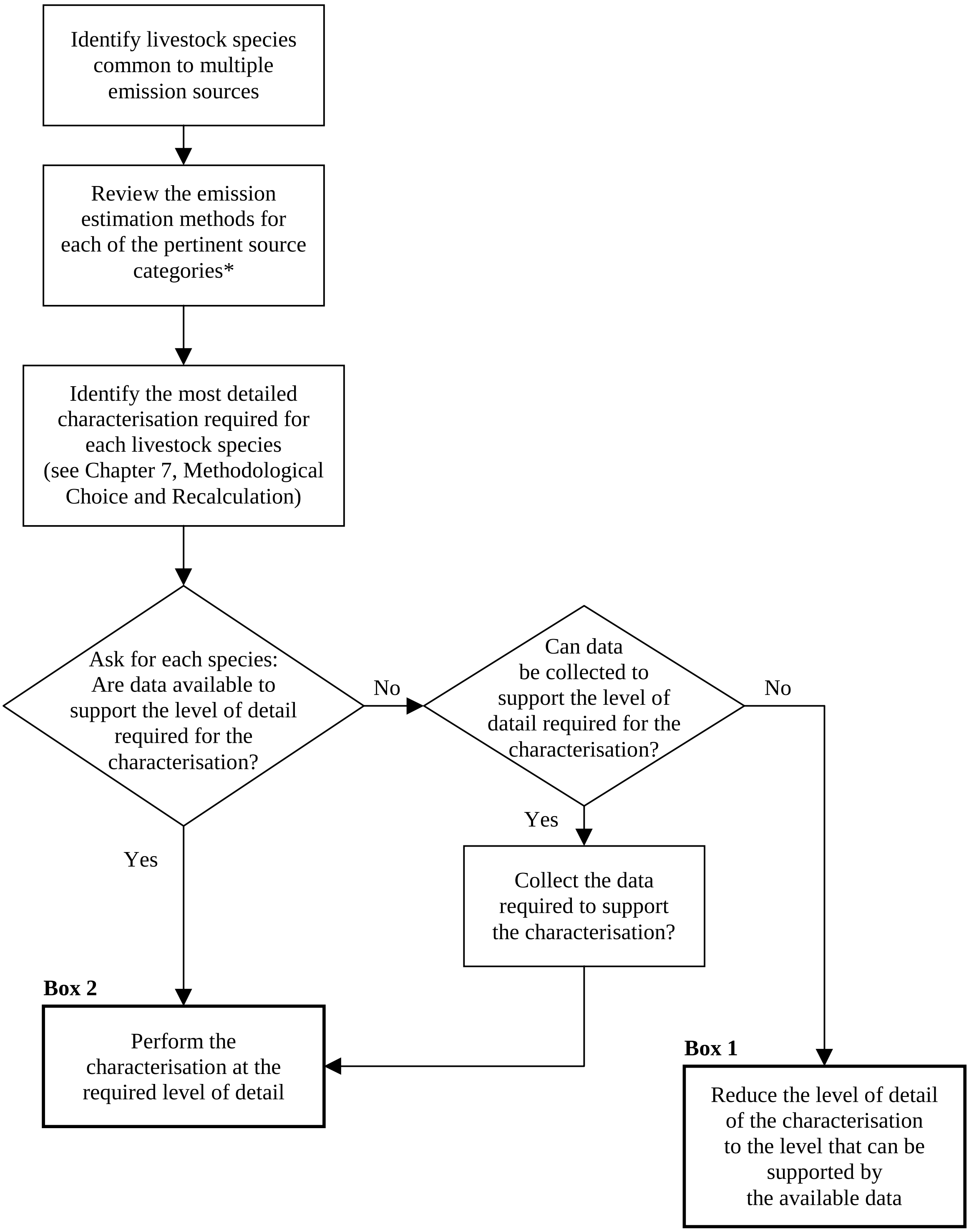
- Section 4.2 - CH_4 emissions from enteric fermentation in domestic livestock;
- Section 4.3 - CH_4 emissions from manure management;
- Section 4.4 - N_2O emissions from manure management;
- Section 4.7 - Direct N_2O emissions from agricultural soils;
- Section 4.8 - Indirect N_2O emissions from nitrogen used in agriculture.

4.1.1.1 CHOICE OF CHARACTERISATION DETAIL

Good practice is to identify the appropriate method for estimating emissions for each source category, and then base the characterisation on the most detailed requirements identified for each livestock species. The livestock characterisation ultimately developed will likely undergo multiple iterations as the needs of each source category are assessed during the emissions estimation process (see Figure 4.1, Decision Tree for Livestock Population Characterisation). The steps required are as follows:

- **Identify the Species Contributing to Multiple Emission Source Categories.** The livestock species that contribute to multiple emission source categories should first be listed. These species are typically: cattle, buffalo, sheep, goats, swine, horses, camels, mules/asses, and poultry.
- **Review the Emission Estimation Method for each of the Pertinent Source Category.** For the source categories of enteric fermentation, CH_4 and N_2O from manure management, as well as direct and indirect N_2O emissions, identify the emission estimating method for that species for that source category. For example, enteric fermentation emissions from cattle, buffalo, and sheep should each be examined to assess whether emissions are large enough to warrant the Tier 2 emissions estimate for each of these species. Similarly, manure management methane emissions from cattle, buffalo, swine, and poultry should be examined to determine whether the Tier 2 emissions estimate is appropriate. Existing inventory estimates can be used to conduct this assessment. If no inventory has been developed to date, Tier 1 emissions estimates should be calculated to provide initial estimates for conducting this assessment. See Chapter 7, Methodological Choice and Recalculation, for guidance on the general issues of methodological choice.
- **Identify the Most Detailed Characterisation Required for each Livestock Species.** Based on the assessments for each species under each source category, identify the most detailed characterisation required to support each emissions estimate for each species. Typically, the ‘Basic’ characterisation can be used across all relevant source categories if the enteric fermentation and manure sources are both estimated with their Tier 1 methods. An ‘Enhanced’ characterisation should be used to estimate emissions across all the relevant sources if the Tier 2 method is used for either enteric fermentation or manure.

Figure 4.1 Decision Tree for Livestock Population Characterisation



*These sources include: CH_4 from Enteric Fermentation, CH_4 from Manure Management, N_2O from Manure Management, Direct N_2O from Agricultural Soils, and Indirect N_2O from Nitrogen used in Agriculture

BASIC CHARACTERISATION

For the 'Basic' Characterisation it is *good practice* to collect the following livestock characterisation data to support the emissions estimates:

Livestock Species and Categories: A complete list of all significant livestock populations that have default emission factor values provided in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*IPCC Guidelines*) must be developed (i.e. dairy cows, other cattle, buffalo, sheep, goats, camels, horses, mules and asses, swine, and poultry).[1] More detailed categories can (and should) be used if the data are available.

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

Milk Production: Average annual milk production for dairy cows is required. Milk production data are used in estimating an emission factor for enteric fermentation using the Tier 1 method. Country-specific data sources are preferred, but FAO data may also be used.

Climate: For some large countries, livestock may be managed in regions with different climates. For each livestock category, the percentage of animals in each climate region should be estimated. In the *IPCC Guidelines*, Reference Manual, Table 4-1, three climate regions are defined in terms of annual average temperature: cool (<15°C), temperate (15°C - 25°C), and warm (>25°C). Livestock population data by region can be developed from country-specific climate maps.

ENHANCED CHARACTERISATION

The 'Enhanced' livestock characterisation provides detailed information on:

- Definitions for livestock sub-categories;
- Livestock population by sub-category;
- Feed intake estimates for the typical animal in each sub-category.

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

The feed intake estimates developed through the 'Enhanced' characterisation are used in the Tier 2 enteric fermentation emissions estimate for cattle, buffalo, and sheep. Additionally, these same feed intake estimates should be used to harmonise the estimated manure and nitrogen excretion rates used to estimate CH_4 and N_2O emissions from manure management and direct and indirect N_2O emissions.

Define Livestock Sub-categories: It is *good practice* to classify cattle and buffalo populations into a minimum of three main sub-categories for each species:

- Cattle: Mature Dairy Cows, Mature Non-Dairy Cattle, and Young Cattle.
- Buffalo: Mature Dairy Buffalo (females only), Mature Non-Dairy Buffalo, and Young Buffalo.

Depending on the level of detail in the implementation of the emissions estimation method, these main categories can be further classified into sub-categories based on animal or feed characteristics. The most common sub-categories for cattle and buffalo are shown in Table 4.1, Representative Cattle and Buffalo Categories, although other sub-categories could be developed in particular countries.

For sheep, the national flock can be disaggregated into categories according to animal and management class as presented in Table 4.2, Representative Sheep Categories. Subdivisions similar to those used for cattle and buffalo can be used to further disaggregate the sheep population with the goal of creating sub-categories with relatively homogenous characteristics.

When completing the Tier 2 manure management methane estimate for swine, it is preferable to classify the swine population into the following sub-categories: sows, boars, and growing animals. Sows could be further

[1] The *IPCC Guidelines* uses the term 'dairy cattle' to refer to cows that have calved at least once and are being kept to produce milk. For good practice, the term 'dairy cattle' has been changed to 'dairy cows' to avoid possible confusion with other cattle (e.g. replacement dairy heifers) connected with the dairy industry. The term 'other cattle' is used to refer to cattle that are not in other defined categories.

classified into farrowing and gestation sows, and growing animals further divided into nursery, growing and finisher pigs. It should be noted, however, that this disaggregation is only necessary if detailed data are available on manure management system usage by these animal species/categories.

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 are generally defined to represent differences in feeding systems and diet.

TABLE 4.1

REPRESENTATIVE CATTLE AND BUFFALO CATEGORIES

Main Categories	**Sub-categories**
Mature Dairy Cows or Mature Dairy Buffalo	• High-producing dairy cows or dairy buffalo that have calved at least once and are used principally for milk production; • Low-producing dairy cows or dairy buffalo that have calved at least once and are used principally for milk production.
Other Mature Cattle or Mature Non-dairy Buffalo	Females: • Cows used principally for producing meat; • Cows used for more than one production purpose: milk, meat, draft. Males: • Bulls used principally for breeding purposes; • Bullocks used principally for draft power; • Steers used principally for producing meat.
Young Cattle or Young Buffaloes	• Pre-Weaned Calves; • Growing cattle or buffaloes; • Feedlot-fed cattle or buffalo on high-grain diets.

Source: *IPCC Guidelines*, Reference Manual, Table 4-7.

TABLE 4.2

REPRESENTATIVE SHEEP CATEGORIES

Main Categories	**Sub-categories**
Mature Ewes	• Breeding ewes where either meat or wool production or both is the primary purpose; • Milking ewes where commercial milk production is the primary purpose.
Other Mature Sheep (>1 year)	• No further sub-categorisation recommended
Young Sheep	• Intact males; • Castrates; • Females.

Source: Lassey and Ulyatt (1999).

Livestock Population by Sub-category: For each livestock sub-category, the average annual population should be estimated in terms of the number of head per year, although in some cases a period of less than a year may be used. Regardless of the length of time chosen, it is important to ensure temporal consistency between the activity data and the emission factor. As far as possible inventory agencies are encouraged to use their own population data from official national statistics or industry sources, but FAO data can be used if necessary. Seasonal births and slaughters may cause the population 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 average annual population, particularly if adjustments to the original data are required.

Feed Intake Estimates: The feed intake of a representative animal in each sub-category is estimated to support the Tier 2 emissions estimates. Feed intake is typically measured in terms of energy (e.g. Mega Joules (MJ) per day) or dry matter (e.g. kilograms (kg) per day). To support the enteric fermentation Tier 2 method (see Section 4.2), detailed data requirements and equations are included in the *IPCC Guidelines* to estimate feed intake. The *good practice guidance* presented below updates the *IPCC Guidelines* for cattle and buffalo to make the equations more applicable to a wider range of animal species/categories and management conditions. In addition, an enhanced characterisation to support the Tier 2 method for sheep is presented, recognising that for some countries sheep are a significant source of emissions. Feed intake for other species can be estimated using similar country-specific methods appropriate for each. The remainder of this sub-section presents the data requirements and equations used to estimate feed intake for cattle, buffalo, and sheep. For all estimates of feed intake, *good practice* is to:

- Collect data to describe the performance of the typical animal in each sub-category;
- Estimate feed intake from the animal performance data for each sub-category.

In some cases, the equations should be applied on a seasonal basis, for example under conditions in which livestock gain weight in one season and lose weight in another.

The following animal performance data are required for each animal sub-category to estimate feed intake for the sub-category:

- *Weight (W), kg*: Live-weight data should be collected for each animal sub-category, and the data should be based on weight measurements of live animals. As it is unrealistic to perform a complete census of live-weights, live-weight data could be obtained from research studies, expert assessments or statistical databases. Live-weight data should be checked to ensure that it is representative of country conditions. Comparing the 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. Additionally it should be noted that the relationship between live-weight and slaughter-weight varies between countries. For cattle, buffalo and mature sheep, the yearly average weight for each animal category (e.g. mature beef cows) is needed. For young sheep, weights are needed at: birth, weaning, one year of age, and at slaughter if slaughter occurs prior to one year.
- *Average weight gain (or loss) per day (WG), kg/d (for cattle and buffalo)*: 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. However, collecting data on weight gain and loss for mature animals may be appropriate for countries with wet and dry seasons or extreme temperatures. Mature animals lose weight during the dry season and under extreme temperatures gain weight during the wet season. In this circumstance, the feed intake would be estimated separately for the wet and dry seasons and hot and cold seasons.
- *Mature weight (MW), kg (for cattle and buffalo)*: The mature weight is the potential body weight of an adult animal were it to reach 28% body fat (NRC 1996). The mature weight will vary among breeds. Mature body weight may be similar to ‘reference weight’ or ‘final shrunk body weight’ values as used in different countries. Estimates of mature weight are typically available from livestock specialists and producers.
- *Average number of hours worked per day*: For draft animals, the average number of hours worked per day must be determined.
- *Feeding situation*: The feeding situation that most accurately represents the animal sub-category must be determined using the definitions shown below. If the feeding situation falls between the definitions, the feeding situation should be described in detail. This detailed information may be needed when calculating the enteric fermentation emissions, because interpolation between the feeding situations may be necessary to assign the most appropriate coefficient. For cattle and buffalo the feeding situations are:

  (i) *Stall or housed* – animals are confined to a small area (i.e. tethered, pen, barn) with the result that they expend very little energy to acquire feed;

  (ii) *Pasture* – animals are confined in areas with sufficient forage requiring modest energy expense to acquire feed;

  (iii) *Grazing large areas* – animals graze open range land or hilly terrain and expend significant energy to acquire feed.

  For sheep, the feeding situations are:

  (i) *Housed ewes* – animals are confined due to pregnancy in final trimester (50 days);

  (ii) *Grazing flat pasture* – animals walk up to 1000 meters per day and expend very little energy to acquire feed;

  (iii) *Grazing hilly pasture* – animals walk up to 5,000 meters per day and expend significant energy to acquire feed;

(iv) *Housed fattening lambs* – animals are housed for fattening.

- *Average milk production per day, kg/d*: These data are for milking ewes, dairy cows and buffalo and other cows or non-dairy buffalo nursing calves. The average daily production should be calculated by dividing the total annual production by 365, or reported as average daily production along with days of lactation per year, or estimated using seasonal production divided by number of days per season. (Note: If using seasonal production data, the emission factor must be developed for that seasonal period).
- *Fat content, %*: Average fat content of milk is required for all lactating cows and buffalo.
- *Percent of females that give birth in a year*: This is collected only for mature cattle, buffalo, and sheep.
- *Feed digestibility, (DE)*: The proportion of energy in the feed not excreted in the feces is known as feed digestibility. The feed digestibility is commonly expressed as a percentage (%). Common ranges of feed digestibility are 50-60% for crop by-products and range lands; 60-75% for good pastures, good preserved forages, and grain supplemented forage-based diets; and 75-85% for grain-based diets fed in feedlots. Digestibility data should be based on measured values for the dominant feeds or forages being consumed, considering seasonal variations. Although a complete census of digestibility is considered unrealistic, at a minimum digestibility data from research studies should be consulted. While developing the digestibility data, associated feed characteristic data should also be recorded when available, such as measured values for Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and crude protein. NDF and ADF are feed characteristics measured in the laboratory that are used to indicate the nutritive value of the feed for ruminant animals. The concentration of crude protein in the feed can be used to estimate nitrogen excretion.
- *Average annual wool production per sheep (kg/yr)*: 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.

The first step in collecting these data should be to research national statistics, industry sources, research studies and FAO statistics. If published data are not available from these sources, interviews of key industry and academic experts can be undertaken. Section 6.2.5 of Chapter 6, Quantifying Uncertainties in Practice, describes how to elicit expert judgement for uncertainty ranges. Similar expert elicitation protocols can be used to obtain the information required for the livestock characterisation if published data and statistics are not available.

The animal performance data are used to estimate gross energy (GE) intake, which is the amount of energy (MJ/day) an animal needs to perform activities such as growth, lactation, and pregnancy. For inventory agencies that have well-documented and recognised country-specific methods for estimating GE intake based on animal performance data, it is *good practice* to use the country-specific methods. All the metabolic functions listed in Table 4.3, Summary of the Equations Used to Estimate Gross Energy Intake for Cattle and Buffalo and for Sheep, should be included in the GE intake estimate. If no country-specific methods are available, GE intake should be calculated using the equations listed in Table 4.3. As shown in the table, separate equations are used to estimate net energy requirements for sheep as compared with cattle and buffalo. The equations used to calculate GE are as follows:

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 tissue is neither gained nor lost (Jurgen, 1988).

EQUATION 4.1

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

Cf_i = a coefficient which varies for each animal category as shown in Table 4.4 (Coefficients for Calculating NE_m)

Weight = live-weight of animal, kg

Activity**:** NE_a is the net energy for activity, that is the energy needed for animals to obtain their food. The net energy for activity was previously termed NE_{feed} in the *IPCC Guidelines*. NE_{feed} is now called NE_a because the net energy refers to the amount of energy the animal expends to acquire its feed and is based on its feeding situation rather than characteristics of the feed itself. As presented in Table 4.3, the equation for estimating NE_a for cattle and buffalo is different from the equation used for sheep.

EQUATION 4.2a

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

C_a = coefficient corresponding to animal's feeding situation (Table 4.5, Activity Coefficients)

NE_m = net energy required by the animal for maintenance (Equation 4.1), MJ/day

EQUATION 4.2b

NET ENERGY FOR ACTIVITY (FOR SHEEP)

$$NE_a = C_a \bullet (\text{weight})$$

Where:

NE_a = net energy for animal activity, MJ/day

C_a = coefficient corresponding to animal's feeding situation (Table 4.5)

weight = live-weight of animal, kg

For Equations 4.2a and 4.2b, the coefficient C_a corresponds to a representative animal's feeding situation as described earlier. Values for C_a are shown in Table 4.5. If a feeding situation falls between the definitions provided or occurs for only part of the year, NE_a must be weighted accordingly.

TABLE 4.3

SUMMARY OF THE EQUATIONS USED TO ESTIMATE GROSS ENERGY INTAKE FOR CATTLE AND BUFFALO AND FOR SHEEP

Metabolic Functions and Other Estimates	Equations for Cattle and Buffalo	Equations for Sheep
Maintenance (NE_m)	Equation 4.1	Equation 4.1
Activity (NE_a)	Equation 4.2a	Equation 4.2b
Growth (NE_g)	Equation 4.3a	Equation 4.3b
Weight Loss ($NE_{mobilized}$).	Equations 4.4a and 4.4b	NA
Lactation (NE_l)*	Equation 4.5a	Equations 4.5b and 4.5c
Draft Power (NE_w)	Equation 4.6	NA
Wool Production (NE_{wool})	NA	Equation 4.7
Pregnancy (NE_p)*	Equation 4.8	Equation 4.8
{NE_{ma}/DE}	Equation 4.9	Equation 4.9
{NE_{ga}/DE}	Equation 4.10	Equation 4.10
Gross Energy	Equation 4.11	Equation 4.11

Source: Beef equations based on NRC (1996) and sheep based on AFRC (1993).

NA means 'not applicable'.

* Applies only to the proportion of females that give birth.

TABLE 4.4 COEFFICIENTS FOR CALCULATING NE_m		
Animal Category	**Cf_i**	**Comments**
Cattle/Buffalo (non-lactating)	0.322	
Cattle/Buffalo (lactating)	0.335	NRC (1989) provides a higher maintenance allowance for lactation
Sheep (lamb to 1 year)	0.236	15% higher for intact males
Sheep (older than 1 year)	0.217	15% higher for intact males
Source: NRC (1984) and AFRC (1993).		

TABLE 4.5 ACTIVITY COEFFICIENTS CORRESPONDING TO ANIMAL'S FEEDING SITUATION		
Situation	**Definition**	**C_a**
CATTLE AND BUFFALO		
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		
Housed ewes	Animals are confined due to pregnancy in final trimester (50 days).	0.0090
Grazing flat pasture	Animals walk up to 1000 meters per day and expend very little energy to acquire feed.	0.0107
Grazing hilly pasture	Animals walk up to 5,000 meters per day and expend significant energy to acquire feed.	0.024
Housed fattening lambs	Animals are housed for fattening.	0.0067
Source: *IPCC Guidelines.*		

***Growth*:** NE_g is the net energy needed for growth (i.e. weight gain). The current NE_g equation based on NRC (NRC, 1996) is different from the NE_g equation in the *IPCC Guidelines*. The main difference is that the current NE_g equation for cattle and buffalo (shown in Equation 4.3a) includes a mature weight-scaling factor. When characterising an animal category that has a net weight loss for a period of time (e.g. cattle during the dry season), do not use Equation 4.3a, go directly to Equation 4.4a or 4.4b. For sheep, NE_g is estimated using Equation 4.3b.

EQUATION 4.3a

NET ENERGY FOR GROWTH (FOR CATTLE AND BUFFALO)

$$NE_g = 4.18 \bullet \{0.0635 \bullet [0.891 \bullet (BW \bullet 0.96) \bullet (478/(C \bullet MW))]^{0.75} \bullet (WG \bullet 0.92)^{1.097}\}$$

Where:

NE_g = net energy needed for growth, MJ/day

BW = the live body weight (BW) of the animal, 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, kg

WG = the daily weight gain, kg/day

EQUATION 4.3b

NET ENERGY FOR GROWTH (FOR SHEEP)

$$NE_g = \{WG_{lamb} \bullet [a + 0.5b (BW_i + BW_f)]\} / (365 \text{ days/year})$$

Where:

NE_g = net energy needed for growth, MJ/day

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

BW_i = the bodyweight at weaning, kg

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

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

The NE_g equation used for sheep includes two constants that vary by animal species/category, and are presented in Table 4.6, Constant for Use in Calculating NE_g for Sheep:

TABLE 4.6

CONSTANTS FOR USE IN CALCULATING NE_g FOR SHEEP

Animal species/category	**a**	**b**
Intact Males	2.5	0.35
Castrates	4.4	0.32
Females	2.1	0.45

Source: AFRC (1993).

***Weight Loss for Cattle and Buffalo*: ** When an animal loses weight, $NE_{mobilised}$ represents the energy in the weight loss that can be used by the animal for maintenance. Weight loss is typically not observed when performing an inventory because data are generally collected to describe the change in weight for a year, and mature cattle and buffalo typically have no net change in weight from one year to the next. However, animals sometimes lose weight during part of the year and gain weight during part of the year. For example, in some countries animals lose weight during the dry season and gain weight during the wet season. Additionally, a high producing dairy cow typically loses weight early in lactation, as body tissues are used to supply energy for milk production. This weight is typically gained back later in the year.

Equations 4.4a and 4.4b are provided for estimating $NE_{mobilised}$ for high-producing lactating dairy cows and for other cattle and buffalo. These equations would typically only be used if feed intake is being estimated for portions of a year during which weight loss is observed.

For lactating dairy cows, approximately 19.7 MJ of NE is mobilised per kilogram of weight loss. Therefore, the $NE_{mobilised}$ is calculated as follows (NRC, 1989):

EQUATION 4.4a

NET ENERGY DUE TO WEIGHT LOSS (FOR LACTATING DAIRY COWS)

$$NE_{mobilised} = 19.7 \bullet \text{Weight Loss}$$

Where:

$NE_{mobilised}$ = net energy due to weight loss (mobilised), MJ/day

Weight Loss = animal weight lost per day, kg/day

Note that weight loss is taken as a negative quantity in Equation 4.4a, such that the estimated $NE_{mobilised}$ is a negative number.

For other cattle and buffalo, the amount of energy mobilised through weight loss is calculated by: (1) inserting the amount of weight lost (kg/day) as a positive number into Equation 4.3a as WG to calculate NE_g; and (2) calculating $NE_{mobilised}$ as negative 0.8 times this NE_g value (NRC, 1996).

EQUATION 4.4b

NET ENERGY DUE TO WEIGHT LOSS (FOR BUFFALO AND OTHER CATTLE)

$$NE_{mobilised} = NE_g \bullet (-0.8)$$

Where:

$NE_{mobilised}$ = net energy due to weight loss (mobilised), MJ/day

NE_g = net energy needed for growth, MJ/day

The result from Equation 4.4b is also a negative number.

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

EQUATION 4.5a

NET ENERGY FOR LACTATION (FOR CATTLE AND BUFFALO)

$$NE_l = \text{kg of milk per day} \bullet (1.47 + 0.40 \bullet \text{Fat})$$

Where:

NE_l = net energy for lactation, MJ/day

Fat = fat content of milk, %

Two methods for estimating the net energy required for lactation (NE_l) are presented for sheep. The first method (Equation 4.5b) is used when the amount of milk produced is known, and the second method (Equation 4.5c) 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 4.5b). 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. Consequently, total annual milk production can be estimated as five times the increase in lamb weight prior to weaning. The daily average milk production is estimated by dividing the resulting estimate by 365 days as shown in Equation 4.5c.

EQUATION 4.5b

NET ENERGY FOR LACTATION FOR SHEEP (MILK PRODUCTION KNOWN)

$$NE_l = \text{kg of milk/day} \bullet EV_{milk}$$

Where:

NE_l = net energy for lactation, MJ/day

EV_{milk} = the energy value for milk. A default value of 4.6 MJ/kg (AFRC, 1993) can be used

EQUATION 4.5C

NET ENERGY FOR LACTATION FOR SHEEP (MILK PRODUCTION UNKNOWN)

$$NE_l = ((5 \bullet WG_{lamb})/365 \text{ days/year}) \bullet EV_{milk}$$

Where:

NE_l = net energy for lactation, MJ/day

WG_{lamb} = the weight gain of the lamb between birth and weaning in kg/day

EV_{milk} = the energy value for milk. A default value of 4.6 MJ/kg (AFRC, 1993) can be used

Equations 4.5b and 4.5c assume that the characterisation is being developed for a full year (365 days). If a shorter period is being characterised (e.g. a wet season), then the number of days must be adjusted accordingly.

***Work*:** NE_w is the net energy for work. It is used to estimate the energy required for draft power for cattle and buffalo. Various authors have summarised the energy intake requirements for providing draft power (e.g. Lawrence, 1985; Bamualim and Kartiarso, 1985; and Ibrahim, 1985). The strenuousness of the work performed by the animal influences the energy requirements, and consequently a wide range of energy requirements have been estimated. The values by Bamualim and Kartiarso show that about 10 percent of a day's NE_m requirements are required per hour for typical work for draft animals. This value is used as follows:

EQUATION 4.6

NET ENERGY FOR WORK (FOR CATTLE AND BUFFALO)

$$NE_w = 0.10 \bullet NE_m \bullet \text{hours of work per day}$$

Where:

NE_w = net energy for work, MJ/day

NE_m = net energy required by the animal for maintenance (Equation 4.1), MJ/day

***Wool Production*:** NE_{wool} is the net energy required for sheep to produce a year of wool. The NE_{wool} is calculated as follows:

EQUATION 4.7

NET ENERGY TO PRODUCE WOOL (FOR SHEEP)

$$NE_{wool} = (EV_{wool} \bullet \text{annual wool production per sheep, kg/year})/(365 \text{ days/year})$$

Where:

NE_{wool} = net energy required to produce a year of wool, MJ/day

EV_{wool} = the energy value of each kg of wool produced (weighed after drying but before scouring)

AFRC provides for EV_{wool} the value 24 MJ/kg. At a typical wool production of about 4 kg/sheep/year, the energy demand will normally be quite small.

***Pregnancy*:** NE_p is the energy required for pregnancy. For cattle and buffalo, the total energy requirement for pregnancy for a 281-day gestation period averaged over an entire year is calculated as 10% of NE_m. For sheep, the NE_p requirement is similarly estimated for the 147-day gestation period, although the percentage varies with the number of lambs born (Table 4.7, Constant for Use in Calculating NE_p in Equation 4.8). Equation 4.8 shows how these estimates are applied.

EQUATION 4.8

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

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

Where:

NE_p = net energy required for pregnancy, MJ/day

$C_{pregnancy}$ = pregnancy coefficient (see Table 4.7)

NE_m = net energy required by the animal for maintenance (Equation 4.1), MJ/day

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

TABLE 4.7 CONSTANTS FOR USE IN CALCULATING NE_p IN EQUATION 4.8	
Animal Category	$C_{pregnancy}$
Cattle and Buffalo	0.10
Sheep	
Single birth	0.077
Double birth (twins)	0.126
Triple birth or more (triplets)	0.150
Source: Estimate for cattle and buffalo developed from data in NRC (1996). Estimates for sheep developed from data in AFRC (1993).	

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

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

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

  Where:

  Double Birth Fraction = [(lambs born) / (pregnant ewes)] – 1

  Single Birth Fraction = 1 – Double Birth Fraction

- If the number of lambs born in a year divided by the number of ewes that are pregnant in a year exceeds 2, then expert judgement should be sought on how to estimate NE_p.

***NE_{ma}/DE*:** For cattle, buffalo and sheep, the ratio of net energy available in a diet for maintenance to digestible energy consumed NE_{ma}/DE is estimated using the following equation:

EQUATION 4.9

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

$$NE_{ma}/DE = 1.123 - (4.092 \bullet 10^{-3} \bullet DE) + [1.126 \bullet 10^{-5} \bullet (DE)^2] - (25.4/DE)$$

Where:

NE_{ma}/DE = ratio of net energy available in a diet for maintenance to digestible energy consumed

DE = digestible energy expressed as a percentage of gross energy

***NE_{ga}/DE*:** For cattle, buffalo and sheep the ratio of net energy available for growth (including wool growth) in a diet to digestible energy consumed NE_{ga}/DE is estimated using the following equation:

EQUATION 4.10

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

$$NE_{ga}/DE = 1.164 - (5.160 \bullet 10^{-3} \bullet DE) + (1.308 \bullet 10^{-5} \bullet (DE)^2) - (37.4/DE)$$

Where:

NE_{ga}/DE = ratio of net energy available for growth in a diet to digestible energy consumed

DE = digestible energy expressed as a percentage of gross energy

Gross Energy, GE**:** As shown in Equation 4.11, GE is derived based on the net energy estimates and the feed characteristics. Equation 4.11 is similar to Equation 4.13 from the *IPCC Guidelines*, but it corrects a typesetting error and changes the subscripts on some of the terms to distinguish between the net energy available in the feed to meet a net energy requirement (i.e. NE_{ga}) and the net energy requirement of the animal (i.e. NE_g). It is *good practice* to use the corrected equation presented as Equation 4.11 below. Although the *IPCC Guidelines* do not present an equation specifically for sheep, Equation 4.11 represents *good practice* for calculating GE requirements for sheep using the results of the equations presented above.

In using Equation 4.11, only those terms relevant to each animal category are used (see Table 4.3).

EQUATION 4.11

GROSS ENERGY FOR CATTLE/BUFFALO AND SHEEP

$$GE = \{[(NE_m + NE_{mobilized} + NE_a + NE_l + NE_w + NE_p)/(NE_{ma}/DE)] + [(NE_g + NE_{wool}) / (NE_{ga}/DE)]\} / (DE/100)$$

Where:

GE = gross energy, MJ/day

NE_m = net energy required by the animal for maintenance (Equation 4.1), MJ/day

$NE_{mobilised}$ = net energy due to weight loss (mobilised) (Equations 4.4a and 4.4b), MJ/day

NE_a = net energy for animal activity (Equations 4.2a and 4.2b), MJ/day

NE_l = net energy for lactation (Equations 4.5a, 4.5b, and 4.5c), MJ/day

NE_w = net energy for work (Equation 4.6), MJ/day

NE_p = net energy required for pregnancy (Equation 4.8), MJ/day

NE_{ma}/DE = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation 4.9)

NE_g = net energy needed for growth (Equations 4.3a and 4.3b), MJ/day

NE_{wool} = net energy required to produce a year of wool (Equation 4.7), MJ/day

NE_{ga}/DE = ratio of net energy available for growth in a diet to digestible energy consumed (Equation 4.10)

DE = digestible energy expressed as a percentage of gross energy

Once the values for GE are calculated for each animal sub-category, the feed intake in units of kilograms of dry matter per day (kg/day) should also be calculated and compared to the weight of the typical animal in the sub-category. To convert from GE in energy units to dry matter intake, divide by the energy density of the feed. A default value of 18.45 MJ/kg can be used if feed-specific information is not available. The resulting daily dry matter intake should be on the order of 1% to 3% of the body weight of the animal.

CHARACTERISATION FOR ANIMALS WITHOUT EMISSION ESTIMATION METHODS

Some countries may have domesticated animals for which there are currently no Tier 1 or Tier 2 emissions estimating methods (e.g. llamas, alpacas, wapiti, emus, and ostriches). *Good practice* in estimating emissions from these animals is to first assess whether their emissions are likely to be significant enough to warrant characterising them and developing country-specific emission factors. Chapter 7, Methodological Choice and Recalculation, presents guidance for assessing the significance of individual source categories within the national inventory. Similar approaches can be used to assess the importance of sub-source categories (i.e. species) within a source category such as enteric fermentation. 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. The characterisation used to support the Tier 2 emissions estimate for enteric fermentation from cattle is one example of how to develop an emission factor. 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
- Non-poultry monogastric animals: swine

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

Approximate emissions factor = [(alpaca weight)$^{0.75}$ / (sheep weight)$^{0.75}$] • sheep emissions factor.

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

4.1.1.2 DEVELOPING A CONSISTENT TIME SERIES

Developing a consistent time series may require estimating past livestock population characteristics. Typically, livestock population, milk production, and meat production data are available from national statistics for the complete time series. The other key attributes, which may not be as easily obtained through a review of past production data records, do not change rapidly, so back-estimating on the basis of ongoing trends (e.g. trends in live-weights) should be reliable. It should be noted, however, that some countries are experiencing rapid changes in livestock populations as a result of economic restructuring and changing market conditions. Additional investigation will be warranted in these circumstances to ensure that an adequate time series is developed. For general *good practice guidance* related to ensuring a consistent time series, see Chapter 7, Methodological Choice and Recalculation.

4.1.1.3 UNCERTAINTY ASSESSMENT

Each data element in the livestock characterisation has associated uncertainty that depends on how data were obtained. The factors that contribute most to the sensitivity of the feed intake estimates should be identified so that efforts are focused on estimating the uncertainties in these factors. The uncertainty of these factors should then be propagated through to the final estimates of feed intake to estimate the total uncertainty of the feed intake estimate.

The uncertainty in livestock population data is larger than typically recognised. There may well be systematic biases in the reporting of the livestock population to national census takers (positive and negative). The migration of livestock within or between countries may lead to double counting or under counting of some animals. Seasonal changes in populations may not be adequately reflected in annual census data. The population data should be examined in cooperation with the national statistical agencies with these factors in mind.

4.1.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. The current IPCC reporting tables do not provide a mechanism for reporting detailed livestock characteristics. It is *good practice* to provide additional tables for reporting detailed livestock characterisation. The detailed livestock characteristics could be reported in a summary table, such as shown in Table A-1 (p. 4.31) and Table A-2 (pp. 4.32-4.33) in Section 4 of the *IPCC Guidelines*, Reference Manual. The sources for the data in the summary table should be identified and cited clearly.

4.1.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to implement quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in the Tier 2 procedures in Chapter 8, QA/QC, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source. The general check of data processing, handling, and reporting could be supplemented with source specific procedures discussed below:

Activity data check

- The inventory agency should check for consistency in the livestock characterisation data that are used in the emission estimates for each of the pertinent source categories. Standard QC checks should verify that there is consistency in the data used across source categories.
- If data are available, the inventory agency should compute the change in total population over time using the population, birth and death rates, slaughter rates, and imports/exports for each of the animal categories or sub-categories and compare this to statistics on total population to ensure consistency. The inventory agency should make this calculation across years (e.g. 1990 to 1991 to 1992, and so on) as well as across seasons within individual years. The analysis across seasons is particularly important in countries with seasonal production conditions that create large variations in livestock populations during the year.
- The inventory agency should compare total production (e.g. meat, milk and wool) for the animal categories and sub-categories with the statistics on total production to ensure consistency.
- Feed intake estimates developed to support the Tier 2 enteric fermentation emissions estimates should be checked for reasonableness. For ruminant animals, the feed intake in dry matter (kg/day) should be on the order of 1% to 3% of the weight of the animals.
- The inventory agency should review QA/QC associated with secondary data sources (e.g. national food and agriculture agencies, agricultural trade associations, agricultural research organisations). Many of the organisations preparing the livestock-related data will have their own procedures for assessing the quality of the data, independent of what the end use of the data may be. If the QA/QC satisfies the minimum activities listed in the QA/QC plan, reference the QC activity conducted by the statistical organisation. If it is inadequate, establish independent QC checks on the secondary data, re-assess the uncertainty of the emissions estimates derived from the data, or reconsider how the data is used.
- The inventory agency should cross-check activity data against other available reference sources. For example, country-specific data should be compared to FAO statistics for livestock population data and milk production data. Investigate large discrepancies.

External review

- The inventory agency should conduct expert peer review on the livestock characterisation data, involving agricultural experts and specialists.

4.2 CH_4 EMISSIONS FROM ENTERIC FERMENTATION IN DOMESTIC LIVESTOCK

4.2.1 Methodological issues

Livestock are produced throughout the world and are a significant source of global methane (CH_4) emissions. The amount of enteric methane emitted is driven primarily by the number of animals, the type of digestive system, and the type and amount of feed consumed. Cattle, buffalo and sheep are the largest sources of enteric methane emissions.

4.2.1.1 CHOICE OF METHOD

To estimate CH_4 emissions from enteric fermentation, the *IPCC Guidelines* recommend multiplying the number of animals for each animal category by an appropriate emissions factor. Emissions from all animal categories are then summed to get total emissions. In order to maintain consistency in underlying data, it is *good practice* to use a single livestock population characterisation as a framework for estimating CH_4 emissions from enteric fermentation as well as CH_4 and N_2O emissions from manure management. The *Livestock Population Characterisation* section (see Section 4.1) provides guidance on preparing the characterisation.

The *IPCC Guidelines* describe two general methods for estimating emissions from enteric fermentation (see Figure 4.2, Decision Tree for CH_4 Emissions from Enteric Fermentation):

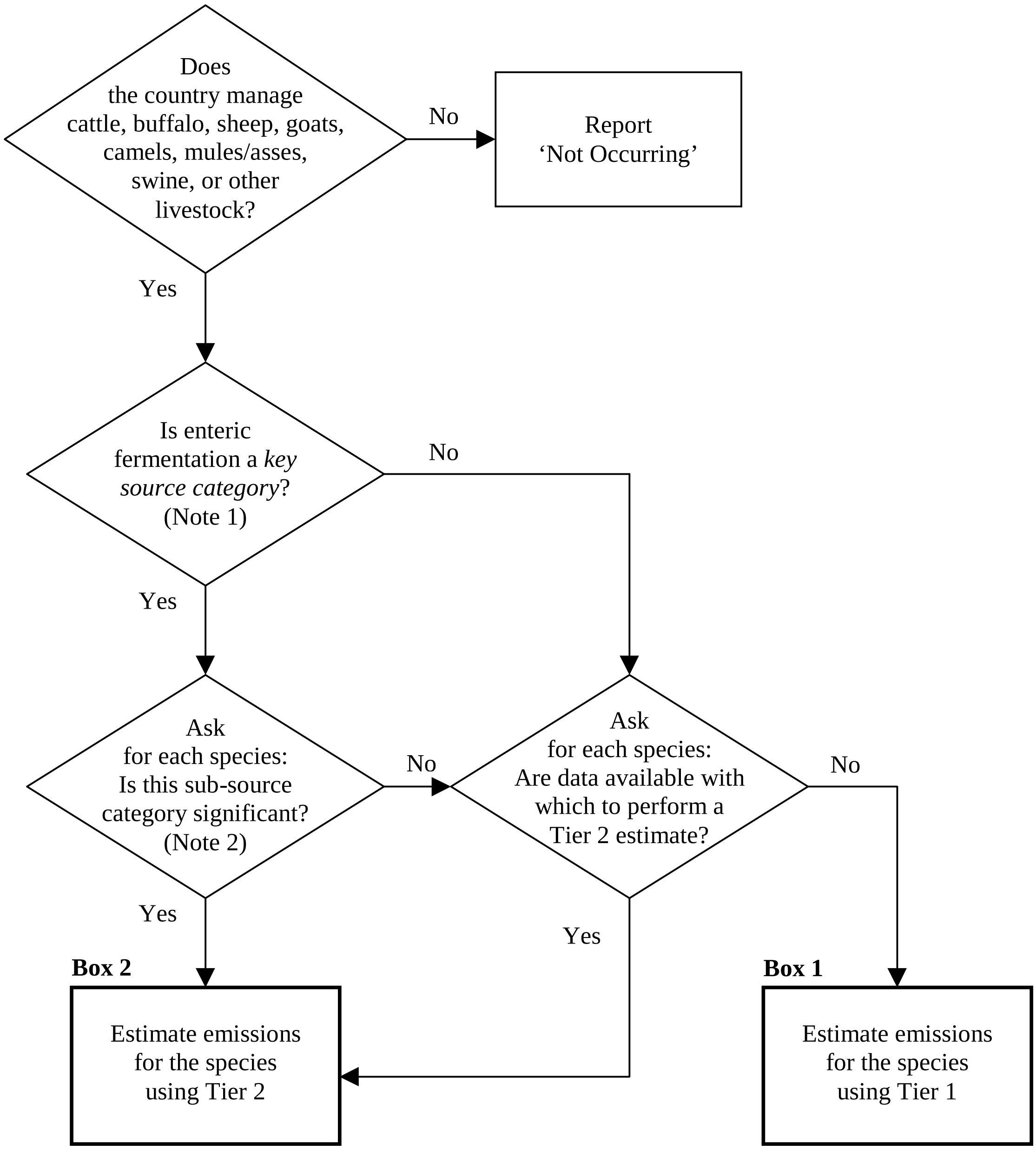
- The Tier 1 method is a simplified approach that relies on default emission factors drawn from previous studies. The Tier 1 approach is likely to be sufficient for many countries and can be used to estimate emissions for the following animals: dairy cows, other cattle, buffalo, sheep, goats, camels, horses, mules, asses and swine.
- The Tier 2 method is a more complex approach that requires detailed country-specific data on nutrient requirements, feed intake and CH_4 conversion rates for specific feed types, which are used to develop emission factors for country-defined livestock categories. The Tier 2 approach should be used if enteric fermentation is a key source category (as defined in Chapter 7, Methodological Choice and Recalculation) for the animal categories that represent a large portion of the country's total emissions.[2]

Tier 1 Method

Under the Tier 1 method, data on livestock categories and milk production should be used to select default emission factors. Tables 4.3 and 4.4 in the Reference Manual of the *IPCC Guidelines* provide default emission factors for each livestock category. As shown in Equation 4.12, the emission factor is multiplied by the number of animals to determine total emissions for each livestock category. Total emissions for this source category are the sum of all livestock categories as shown in Equation 4.13. It is *good practice* to review the Tier 1 emission factors to ensure that the underlying animal characteristics such as weight, growth rate and milk production used to develop them are similar to the conditions in the country. The *IPCC Guidelines* currently provide detailed information for cattle and buffalo. These data should be reviewed by livestock experts in the country and if the underlying characteristics are significantly different, the emission factors should be adjusted accordingly.

[2] 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 approach and are based on well-documented research (if it is determined that emissions from these animals are significant). See Section 4.1 under the heading 'Characterisation for Animals Without Emission Estimation Methods' for more information.

Figure 4.2 Decision Tree for CH_4 Emissions from Enteric Fermentation



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

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

EQUATION 4.12

EMISSIONS FROM A LIVESTOCK CATEGORY

$$\text{Emissions} = \text{EF} \bullet \text{population}/(10^6 \text{ kg/Gg})$$

Where:

Emissions = methane emissions from enteric fermentation, Gg CH_4/year

EF = emission factor for the specific population, kg/head/year

Population = the number of animals, head

EQUATION 4.13

TOTAL EMISSIONS FROM LIVESTOCK

$$\text{Total } CH_4 \text{ Emissions} = \sum_i E_i$$

Where:

Total Emissions = total methane emissions from enteric fermentation, Gg CH_4/year

index i = sums all livestock categories and sub-categories

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

Tier 2 Method

The Tier 2 method also uses Equation 4.12 to calculate emissions, but applies it to more disaggregated livestock population categories and uses calculated emission factors, as opposed to default values. Equation 4.13 should be used to sum the emissions from the disaggregated categories of livestock species for all livestock species to obtain the total emissions for a country. The key issues for the Tier 2 method are the development of emission factors and the collection of detailed activity data. The development of emission factors is described in the next section. Issues related to the collection of activity data are covered in Section 4.1, Livestock Population Characterisation.

4.2.1.2 CHOICE OF EMISSION FACTORS

When the Tier 1 method is used, default emission factors should be taken from the *IPCC Guidelines* Tables 4-3 and 4-4, unless documented country-specific factors are available. When Tier 2 methods are used, in contrast, emission factors specific to the country and its animal species/categories need to be developed. As described in Chapter 7, Methodological Choice and Recalculation, inventory agencies are encouraged to determine what source sub-categories are significant, as some species are likely to represent the major share of enteric fermentation emissions. It is considered *good practice* to develop disaggregated emission factors for those sub-categories that are most significant in terms of emissions.

When the Tier 2 method is used, emission factors are estimated for each animal category using the detailed data developed through the livestock characterisation as set out in the Livestock Population Characterisation section (see Section 4.1). The *IPCC Guidelines* discuss how to develop emission factors for cattle. G*ood practice* in developing these factors is discussed below. In the absence of data for buffalo, the approach described for cattle can be applied to buffalo, given the similarities between these bovine species. In addition, *good practice* for developing sheep emission factors is described below, since this is an important animal species in many countries.

An emission factor for each animal category should be developed using Equation 4.14:

EQUATION 4.14

EMISSION FACTOR DEVELOPMENT

$$EF = (GE \bullet Y_m \bullet 365 \text{ days/yr}) \ / \ (55.65 \text{ MJ/kg } CH_4)$$

Where:

EF = emission factor, kg CH_4/head/yr

GE = gross energy intake, MJ/head/day

Y_m = methane conversion rate which is the fraction of gross energy in feed converted to methane

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

The gross energy intake value (GE) for each animal category is taken from the livestock characterisation presented in Section 4.1.

Obtaining the Methane Conversion Rate (Y_m)

The extent to which feed energy is converted to CH_4 depends on several interacting feed and animal factors. If CH_4 conversion rates are unavailable from country-specific research, the values provided in Table 4.8, Cattle/Buffalo CH_4 Conversion Rates, can be used for cattle and buffalo. These general estimates are a rough guide based on the general feed characteristics and production practices found in many developed and developing countries. When good feed is available (i.e. high digestibility and high energy value) the lower bounds should be used. When poorer feed is available, the higher bounds are more appropriate. A CH_4 conversion rate of zero is assumed for all juveniles consuming only milk (i.e. milk-fed lambs as well as calves).

Due to the importance of Y_m in driving emissions, substantial ongoing research is aimed at improving estimates of Y_m for different animals and feed combinations. Such improvement is most needed for animals fed on tropical pastures as the available data is sparse. For example, a recent study (Kurihara *et al.*, 1999) observed Y_m values outside the ranges described in Table 4.8.

TABLE 4.8

CATTLE/BUFFALO CH_4 CONVERSION RATES (Y_m)

Countries	Livestock type	Y_m [b]
Developed Countries	Feedlot fed cattle [a]	0.04 $\pm$ 0.005
	All other cattle	0.06 $\pm$ 0.005
Developing Countries	Dairy cows (cattle and buffalo) and their young	0.06 $\pm$ 0.005
	Other cattle and buffaloes that are primarily fed low quality crop residues and by-products	0.07 $\pm$ 0.005
	Other cattle or buffalo in Africa - grazing	0.07 $\pm$ 0.005
	Other cattle or buffalo in developing countries other than Africa-grazing	0.06 $\pm$ 0.005

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

[b] The ± values represent the range.

Source: *IPCC Guidelines.*

The Y_m value for sheep may not be the same as for cattle. Lassey *et al.* (1997) suggest that the Y_m for 8-month-old lambs is less (0.045) than for lactating dairy cows (0.062) fed near-identical high quality pasture. Sheep should not be viewed as merely small cattle as far as nutritional performance is concerned, as they differ behaviourally (feed selection) and may also differ in their rumen microbiology. Using Table 4.9, Sheep CH_4 Conversion Rates, Y_m values are selected according to feed quality (as measured by digestibility) and sheep maturity. They are based on data by Lassey *et al.* (1997), Judd *et al.* (1999) and on unpublished data from the same research group [K.R. Lassey and M.J. Ulyatt, personal communication]. The median of each range may be adopted, including 0.07 for mature sheep on all pastures. These values are consistent with measurements by other researchers (Murray *et al.*, 1998; Leuning *et al.*, 1999) but may not span the full range of pastures that may be found.

TABLE 4.9
SHEEP CH_4 CONVERSION RATES (Y_m)

Category	Diets less than 65% digestible	Diets greater than 65% digestible
Lambs (<1 year old)	0.06 ± 0.005	0.05 ± 0.005
Mature sheep	0.07	0.07

Note: The ± values represent the range.

Source: Lassey *et al.* (1997); Lassey and Ulyatt (1999).

4.2.1.3 CHOICE OF ACTIVITY DATA

The activity data should be collected following the guidance from the Livestock Population Characterisation section (see Section 4.1). This approach will ensure consistency with the other related source categories.

4.2.1.4 COMPLETENESS

It is likely that all the major animals managed in the country are known. Consequently, completeness should be achievable. In the event that animals are included in the inventory for which default data are not available and for which no guidelines are provided, the emissions estimate should be developed using the same general principles presented in the discussion of how to develop Tier 2 emission factors.

4.2.1.5 DEVELOPING A CONSISTENT TIME SERIES

The key issues associated with developing a consistent time series are discussed in the Livestock Population Characterisation section (Section 4.1). Care must be taken to use a consistent set of estimates for the CH_4 conversion rate over time. In some cases, there may be reasons to modify these values of methane conversion rates over time. These changes may be due to the implementation of explicit greenhouse gas (GHG) mitigation measures, or may be due to changing agricultural practices such as feed conditions or other management factors without regard to GHGs. Regardless of the driver of change, the data and methane conversion rates used to estimate emissions must reflect the change in data and methods, and the results must be thoroughly documented. If methane conversion rates over a time series are affected by a change in farm practices and/or the implementation of GHG mitigation measures, the inventory agency is encouraged to ensure that the inventory data reflect these practices and that the inventory text thoroughly explains how the change in farm practices and/or implementation of mitigation measures has affected the time series of methane conversion rates. For general *good practice* guidance on developing a consistent time series, see Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2.

4.2.1.6 UNCERTAINTY ASSESSMENT

Below is a description of the major uncertainty issues for the Tier 1 and Tier 2 methods.

Tier 1 Method

As the emission factors for the Tier 1 method are not based on country-specific data, they may not accurately represent a country’s livestock characteristics, and may be highly uncertain as a result. Emission factors estimated using the Tier 1 method are unlikely to be known more accurately than ± 30% and may be uncertain to ± 50%.

There will be an added uncertainty associated with the livestock population characterisation (see Section 4.1) which can be minimised provided the *good practice* approach to agricultural census data outlined in the section on livestock population characterisation is followed.

Tier 2 Method

The uncertainty under the Tier 2 approach will depend on the accuracy of the livestock characterisation (e.g. homogeneity of livestock categories), and also on the extent to which the methods for defining the coefficients in the various relationships that make up the net energy approach correspond to national circumstances. Improving the livestock characterisation will often be the priority in reducing overall uncertainty. Emission factor estimates using the Tier 2 method are likely to be in the order of ± 20%. Inventory agencies using the Tier 2 method are encouraged to undertake an analysis of uncertainties reflecting their particular situation, and in the absence of this analysis the uncertainty under the Tier 2 method should be assumed similar to the uncertainty under the Tier 1 method.

4.2.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. To improve transparency, emission estimates from this source category should be reported along with the activity data and emission factors used to determine the estimates.

The following information should be documented:

- All activity data, including :
  - (i) Animal population data by category and region.
- Activity data documentation including:
  - (i) The sources of all activity data used in the calculations (i.e. complete citation for the statistical database from which data were collected);
  - (ii) The information and assumptions that were used to develop the activity data, in cases where activity data were not directly available from databases;
  - (iii) The frequency of data collection, and estimates of accuracy and precision.
- If the Tier 1 method is used, all default emission factors used in the emissions estimations for the specific animal categories
- If the Tier 2 method is used
  - (i) Values for Y_m;
  - (ii) GE values estimated or taken from other studies;
  - (iii) Documentation of the data used, including their references.

In inventories in which country- or region-specific emission factors were used or in which new methods (other than those described in the *IPCC Guidelines*) were used, the scientific basis of these emission factors and methods should be documented. Documentation should include definitions of input parameters providing a description of the process by which these emission factors and methods are derived, as well as describing sources and magnitudes of uncertainties.

4.2.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to implement quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category. In addition to the guidance in Chapter 8, QA/QC, specific procedures of relevance to this source category are outlined below:

Review of emission factors

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

External review

- If the Tier 2 method is being used, the inventory agency should conduct expert peer review, including from industry, academic institutions, and extension expertise.
- It is important to maintain internal documentation on review results.

4.3 CH_4 EMISSIONS FROM MANURE MANAGEMENT

4.3.1 Methodological issues

Livestock manure is principally composed of organic material. When this organic material decomposes in an anaerobic environment, methanogenic bacteria produce methane (CH_4). These conditions often occur when large numbers of animals are managed in confined areas (e.g. dairy, swine and poultry farms, and beef feedlots, where manure is typically stored in large piles or disposed of in storage tanks or lagoons).

4.3.1.1 CHOICE OF METHOD

To estimate emissions of CH_4 from manure management systems, the animal population must first be divided into the appropriate species and categories to reflect the varying amounts of manure produced per animal and the manner in which the manure is handled. Detailed information on how to characterise the livestock population for this source is provided in the section on Livestock Population Characterisation (see Section 4.1).

As described in the *IPCC Guidelines*, the four main steps used to estimate CH_4 emissions from livestock manure are as follows:

(i) Collect population data from Livestock Population Characterisation;

(ii) Use default IPCC emission factors or develop emission factors on the basis of manure characteristics (B_o, VS, MCF) for each relevant livestock population (species, category or subcategory) and manure management system;

(iii) Multiply each emission factor by the defined livestock population to obtain the CH_4 emission estimate for that livestock population;

(iv) Sum emissions from all defined livestock population to determine national emissions.

Emission estimates should be reported in gigagrams (Gg). As the emission factors are to be reported in kilograms per head per year, the emissions are divided by 10^6. Equation 4.15 shows how to calculate emissions for a defined population:

EQUATION 4.15

CH_4 EMISSION FROM MANURE MANAGEMENT

$$CH_4 \text{ Emissions}_{(mm)} = \text{Emission Factor} \bullet \text{Population} \ / \ (10^6 \text{ kg/Gg})$$

Where:

CH_4 Emissions$_{(mm)}$ = CH_4 emissions from manure management, for a defined population Gg/year

Emission Factor = emission factor for the defined livestock population, kg/head/year

Population = the number of head in the defined livestock population

The *IPCC Guidelines* include two tiers to estimate CH_4 emissions from livestock manure. The Tier 1 approach is a simplified method that only requires livestock population data by animal species/category and climate region (cool, temperate, warm), in order to estimate emissions.

The Tier 2 approach provides a detailed method for estimating CH_4 emissions from manure management systems, and is encouraged to be used for countries where a particular livestock species/category represents a significant share of emissions. This method requires detailed information on animal characteristics and the manner in which manure is managed. Using this information, emission factors are developed that are specific to the conditions of the country.

The method chosen will depend on data availability and natural 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 factors. The Tier 1 approach should only be used if all possible avenues to use the Tier 2 approach have been exhausted. The process for determining which tier to use is shown in the decision tree (see Figure 4.3).

4.3.1.2 CHOICE OF EMISSION FACTORS

The ideal means of determining emission factors is to conduct non-invasive or non-disturbing measurements of emissions in actual production systems (feedlot, pasture). These field results can be used to develop models to estimate emission factors. Such measurements are difficult to conduct, however, and require significant resources, unique expertise, and equipment that may not be available. Thus, while such an approach is recommended to improve accuracy, it is not necessarily required for *good practice* depending on national circumstances.

When using the Tier 1 method, default emission factors are used. Default emission factors are presented in Table 4-6 of the *IPCC Guidelines*, Reference Manual for each of the recommended population subgroups.[3]

If region-specific or country-specific measurement data are not available, Tier 2 emission factors should be developed using the method described in the *IPCC Guidelines*. The process of developing Tier 2 emission factors involves determining the mass of volatile solids excreted by the animals (VS, in kg) along with the maximum CH_4 producing capacity for the manure (B_o, in m^3/kg of VS). In addition, a CH_4 conversion factor (MCF) that accounts for the influence of climate on CH_4 production must be obtained for each manure management system.

As emissions can vary significantly by region and animal species/category, emission estimates should reflect to the maximum extent 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 periodically updated to account for changes in manure management practices, animal characteristics, and technologies. These revisions should be based on the most reliable scientifically reviewed data available. Frequent monitoring is desirable to verify key model parameters, but this may not be feasible.

VS Excretion Rates: The best way to obtain average daily VS excretion rates is to use data from country-specific 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 the Livestock Population Characterisation section (see Section 4.1). This will also assure consistency in the data underlying the emissions estimates. For swine, country-specific swine production data may be required to estimate feed intake. Once feed intake is estimated, the VS excretion rate is estimated as:

EQUATION 4.16

VOLATILE SOLID EXCRETION RATES

$$VS = GE \bullet (1 \text{ kg-dm}/18.45 \text{ MJ}) \bullet (1 - DE/100) \bullet (1 - ASH/100)$$

Where:

VS = volatile solid excretion per day on a dry-matter weight basis, kg-dm/day

GE = Estimated daily average feed intake in MJ/day

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

ASH = Ash content of the manure in percent (e.g. 8%)

Note: The value 18.45 is the energy density of feed expressed in MJ per kg dry matter. This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

For cattle, the DE value used should be the value used in the 'Enhanced' characterisation method described in the Livestock Population Characterisation (see Section 4.1). The ash content of cattle and buffalo manure is generally around 8% (IPCC,1996). For swine, default values for digestibility are 75% and 50% for developed

[3] It should be noted, however, that there is an error in Table 4-6 of the *IPCC Guidelines*. The error is the default CH_4 emission factor for non-dairy cattle in temperate regions in Latin America. The value should be 1 instead of 2, as shown correctly in Appendix B of the *IPCC Guidelines*, Vol. 3.

and developing countries, respectively. As to ash content, values of 2% and 4% can be used for developed and developing countries, respectively (IPCC, 1996).

If country-specific VS values cannot be developed, the default VS production rates presented in the *IPCC Guidelines* Reference Manual (Tables B1-B7) can be used. These default factors were developed based on average feed intake and feed digestibility data, and are considered reasonably reliable.

B_o values: The preferred method to obtain B_o measurement values is to use data from country-specific published sources, measured with a standardised method. It is important to standardise the B_o measurement, including the way of sampling. If country-specific B_o measurement values are not available, default values are provided in Appendix B of the *IPCC Guidelines*, Reference Manual.[4]

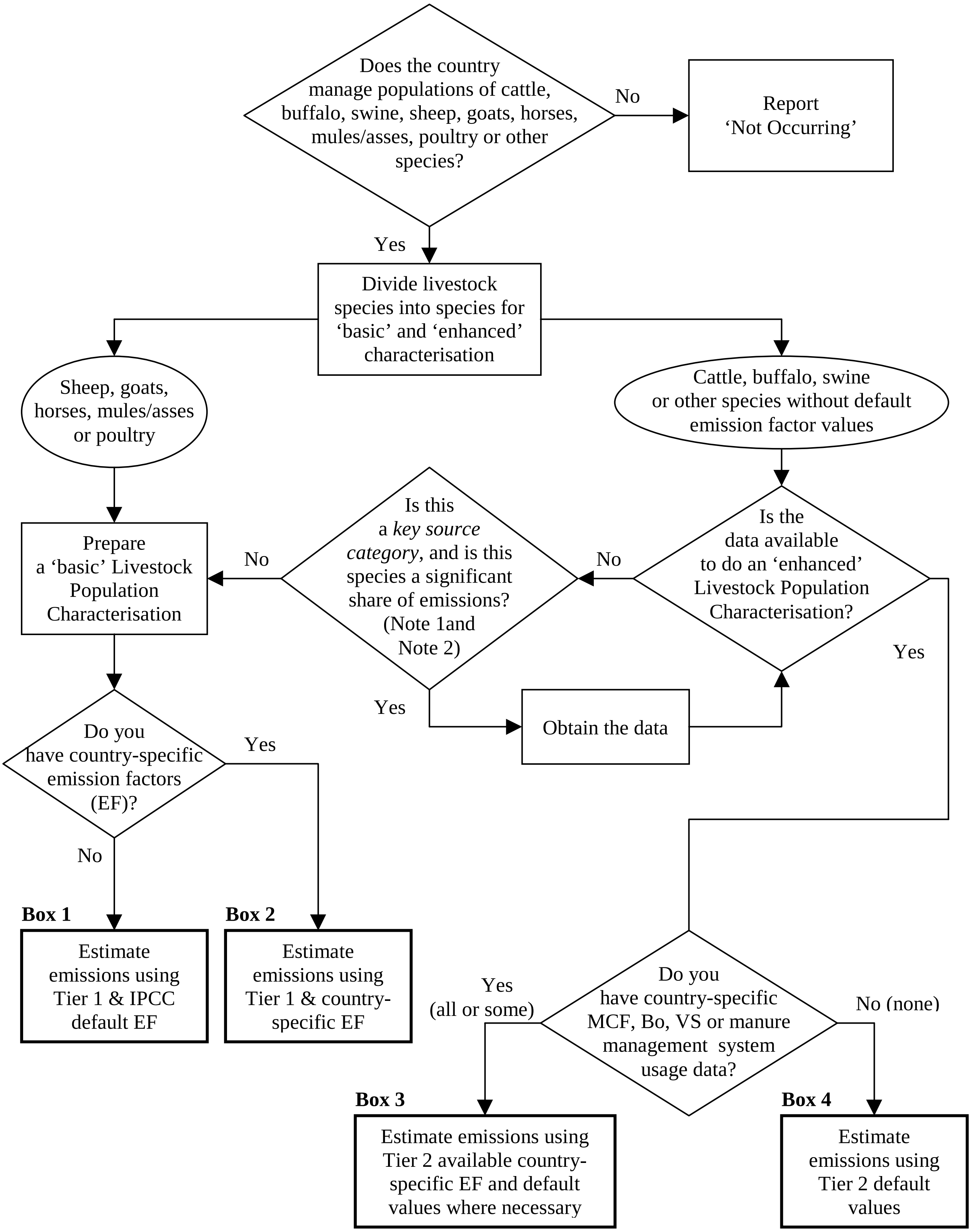
MCF Values: Default MCF values are provided in the *IPCC Guidelines* for different manure management systems and climate zones. These default values may not, however, encompass the potentially wide variation within the defined categories of management systems. Therefore, country-specific MCFs that reflect the specific management systems used in particular countries or regions should be developed as far as 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 laboratory-based default MCF values. Measurements should include the following factors:

- Timing of storage/application;
- Length of storage;
- Manure characteristics;
- Determination of the amount of manure left in the storage facility (methanogenic inoculum);
- Time and temperature distribution between indoor and outdoor storage;
- Daily temperature fluctuation;
- Seasonal temperature variation.

If country-specific MCF measurements are not available, default MCF values are presented in the *IPCC Guidelines* Reference Manual (Table 4-8). Some of these default values are revised as shown in Table 4.10, MCF Values for Manure Management Systems Defined in the *IPCC Guidelines*, (revisions are in italics). The revisions in Table 4.10 present an approach for subdividing digester and anaerobic lagoon systems to account for the recovery, flaring and use of biogas. Such subdivision is important in order to account for policy measures that encourage CH_4 recovery from these systems. Table 4.11, MCF Values for Manure Management Systems not Specified in the Guidelines, presents MCF values for some additional manure management systems currently in use in various countries that were not specifically addressed in the *IPCC Guidelines*. In countries where these systems are in use, disaggregation into these categories is encouraged. The default MCF values presented in Table 4.11 can be used if country-specific values are unavailable.

[4] When choosing default B_o values, if the production practices in the developing country are similar to those in developed countries, then the value for developed countries should be chosen.

Figure 4.3 Decision Tree for CH_4 Emissions from Manure Management



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

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

Emission Factor Equation: Equation 4.17 shows how to calculate the emission factor for CH_4 from manure management:

EQUATION 4.17
EMISSION FACTOR FROM MANURE MANAGEMENT

$$EF_i = VS_i \bullet 365 \text{ days/year} \bullet B_{o_i} \bullet 0.67 \text{ kg/m}^3 \bullet \sum_{(jk)} MCF_{jk} \bullet MS_{ijk}$$

Where:

EF_i = annual emission factor for defined livestock population *i*, in kg

VS_i = daily VS excreted for an animal within defined population *i*, in kg

B_{o_i} = maximum CH_4 producing capacity for manure produced by an animal within defined population *i*, m^3/kg of VS

MCF_{jk} = CH_4 conversion factors for each manure management system *j* by climate region *k*

MS_{ijk} = fraction of animal species/category *i*'s manure handled using manure system *j* in climate region *k*

4.3.1.3 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 the Livestock Population Characterisation section (see Section 4.1). As noted in the section, the *good practice* method for characterising livestock populations is to conduct a single 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 this source category 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.

Inventory agencies in countries with varied climatic conditions are encouraged to obtain population data for each major climatic zone. Such an effort will improve accuracy because CH_4 emissions from manure management systems can vary considerably depending on the climate. Ideally, the regional breakdown can be obtained from published national 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.

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. Chapter 6, Quantifying Uncertainties in Practice, Section 6.2.5, describes how to elicit expert judgement for uncertainty ranges. Similar expert elicitation protocols can be used to obtain manure management system distribution data.

For a regional emissions analysis, it is important that regional data for both population and manure management system usage is used. Additionally, information on climatic differences among regions within a country must be obtained so that the proper MCFs can be applied. If all of these data are not available at a regional level, a regional analysis will not be more accurate than a national-level emissions study.

4.3.1.4 COMPLETENESS

A complete inventory will include emissions estimates from all domesticated animal population manure sources in a country, regardless of the tier that is applied. The listed IPCC animal population categories are distinct and population data are generally available from national references or the FAO. Thus, inventory agencies should be able to develop an emissions estimate that encompasses all of the required animal population species.

4.3.1.5 DEVELOPING A CONSISTENT TIME SERIES

Developing a consistent time series for the Tier 1 method requires collecting and compiling animal population and manure management data during the time period. For the Tier 1 method, difficulties arise when:

- Animal population data are not available for the entire period;
- Animal population data over the entire period are not broken down into the animal species/categories recommended by IPCC;
- Changes in manure management practices over time affect CH_4 emissions.

Animal population data can be obtained by collecting aggregate historical data from FAO and using current data to break out historical population data into the animal groups. If significant changes in manure management practices have occurred over time, the Tier 1 method will not provide an accurate time series of emissions, and the Tier 2 method should be considered.

In addition to the data issues described for the Tier 1 method, developing a time series for the Tier 2 method requires the collection and compilation of country-specific manure management system data. Difficulties arise in the Tier 2 method when:

- Manure management system data are not available for some period during the time series;
- Manure management system data are not broken down into the systems recommended by IPCC;
- The Tier 2 method was not used throughout the time series.

The lack of reliable manure management system data can be addressed by extrapolating manure management system trends from a sample area or region to the entire country, if climatic conditions are similar (i.e. temperature and rainfall). If the emission estimation method has changed, historical data that are required by the current method should be collected and used to recalculate emissions for that period. If such data are not available, it may be appropriate to create a trend with recent data and use the trend to back-estimate management practices for the time series. Among other sources, publications and industry and university experts can be used to develop trends for the animal population and manure characteristics. Chapter 7, Methodological Choice and Recalculation, provides guidance on how to address these issues. Section 4.1 suggests approaches for the animal population aspects.

4.3.1.6 UNCERTAINTY ASSESSMENT

Expert judgement will, in the probable absence of extensive empirical data, be required to assess uncertainties for this source. Chapter 6, Quantifying Uncertainties in Practice, provides advice for obtaining expert judgements and combining them with other uncertainties.

Experts can estimate uncertainty by evaluating the various components of the emission estimate. The major sources of uncertainty are the accuracy of emission factors, manure management system distribution, and activity data. The default values (either Tier 1 or 2 method) may have a large uncertainty for an individual country, because they may not reflect the actual conditions within the country. Uncertainties can be reduced by developing and using a model that relates MCF and B_o values to different country/region specific factors.

TABLE 4.10

MCF VALUES FOR MANURE MANAGEMENT SYSTEMS DEFINED IN THE *IPCC GUIDELINES* (REVISIONS ARE NOTED IN ITALICS)

SYSTEM	DEFINITION	MCFs BY CLIMATE			COMMENTS
		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%	
Daily Spread	*Dung and urine are collected by some means such as scraping. The collected waste is applied to fields.*	0.1%	0.5%	1%	
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.*	1%	1.5%	2%	
Dry lot	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%	
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 may be added.*	*39%*	*45%*	*72%*	When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to formula 1.
Anaerobic Lagoon	Characterised by flush systems that use water to transport manure to lagoons. The manure resides in the lagoon for period from 30 days to over 200 days. The water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields.	*0-100%*	*0-100%*	*0-100%*	Should be subdivided in different categories, considering % recovery of the biogas and flaring of the biogas . Calculation with formula 1.
Pit Storage below animal confinements	*Combined storage of dung and urine below animal confinements:* *<1 month* *>1 month*	*0* *39%*	*0* *45%*	*30%* *72%*	When pits used as fed-batch storage/digesters, MCF should be calculated according to formula 1. Note that the ambient temperature, not the stable temperature is to be used for determining the climatic conditions.
Anaerobic Digester	*The dung and urine in liquid/slurry are collected and anaerobically digested. CH4 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.*	*10%*	*10%*	*10%*	

Source: *IPCC Guidelines* and Judgement by Expert Group (see Co-chairs, Editors and Experts; CH_4 Emissions from Manure Management).

Formula 1:

$MCF = [\{CH_{4\ prod} - CH_{4\ used} - CH_{4\ flared} + MCF_{storage} * (B_o - CH_{4\ prod})\}/ B_o] *100\%$

Where:

$CH_{4\ prod}$ = methane production in digester , (l CH_4/gVS added). Note: When a gas tight coverage of the storage for digested manure is used, the gas production of the storage should be included.

$CH_{4\ used}$ = amount of methane gas used for energy, (l CH_4/gVS added)

$CH_{4\ flared}$ = amount of methane flared, (l CH_4/gVS added)

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

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

TABLE 4.11

MCF VALUES FOR MANURE MANAGEMENT SYSTEMS NOT SPECIFIED IN THE *IPCC GUIDELINES* (JUDGEMENT BY EXPERT GROUP)

Additional Systems	Definition	MCFs by Climate			Comments
		Cool	Temperate	Warm	
Cattle and Swine Deep Litter	Cattle/swine dung and urine are excreted on stall floor. The accumulated waste is removed after a long time.				
	<1 month	0	0	30%	MCF's are similar to liquid/slurry; temperature dependant.
	>1 month	39%	45%	72%	
Composting - Intensive	Dung and urine are 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 urine are 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. Aerobic treatment results in large accumulations of sludge. 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.

Source: Judgement by Expert Group (see Co-chairs, Editors and Experts; CH_4 Emissions from Manure Management).

4.3.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. To improve transparency, emission estimates from this source category should be reported along with the activity data and emission factors used to determine the estimates.

The following information should be documented:

- All activity data, including:
  - (i) Animal population data by species/category and by region if applicable;
  - (ii) Climatic conditions in regions if applicable;[5]
  - (iii) Manure management system data, by animal species/category and by region, if applicable.
- Activity data documentation, including:
  - (i) The sources of all activity data used in the calculations (i.e. complete citations for the statistical database from which data were collected), and in cases where activity data were not available directly from databases, the information and assumptions that were used to derive the activity data;
  - (ii) The frequency of data collection, and estimates of accuracy and precision.
- If the Tier 1 method is used, all default emission factors used in the emissions estimation for the specific animal population species/category.
- If the Tier 2 method is used, emission factor calculation components, including:
  - (i) VS and B_o values for all animal population types in inventory, whether country-specific, region-specific, or IPCC default.
  - (ii) MCF values for all manure management systems used, whether country-specific or IPCC default.
- Emission factors documentation, including:
  - (i) References for the emission factors that were used (IPCC default or otherwise).
  - (ii) The scientific basis of these emission factors and methods, including definition of input parameters and description of the process by which these emission factors and methods are derived, as well as describing sources and magnitudes of uncertainties. (In inventories, in which country- or region-specific emission factors were used or in which new methods other than those described in the *IPCC Guidelines* were used).

4.3.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to implement quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, 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, as outlined in Chapter 8, QA/QC, could be supplemented with procedures discussed below:

Activity data check

- The inventory agency should review data collection methods, checking the data to ensure they were collected and aggregated correctly. The data should be cross-checked with previous years to ensure the data are reasonable. Inventory agencies should document data collection methods, identify potential areas of bias, and evaluate the representativeness of the data.

[5] e.g. average temperature during manure storage.

Review of emission factors

- If using defaults, the inventory agency should review the available default emission factor values and document the rationale for selecting specific values.
- If using the Tier 2 method (i.e. where country-specific emission factors by animal and manure management type are used to calculate emissions), the inventory agency should cross-check the country-specific factor parameters (i.e. VS excretion rates, $B_{o,}$ and MCF) against the IPCC defaults. Significant differences between country-specific parameters and default parameters should be explained and documented.
- If using the Tier 1 method (using default IPCC emission factors), the inventory agency should evaluate how well the default VS excretion rates and B_o values represent the defined animal population and manure characteristics of the country.
- Any available country-specific data should be used to verify relevant default components.
- Inventory agency should review the method used to determine the country- or region-specific VS and B_o values, particularly in terms of the standardised procedures previously described. A detailed description of the equations used to estimate emission factors should be reviewed as well, including the numbers used in each calculation and the source of any data collected.

External review

- If using the Tier 2 method, the inventory agency should conduct an expert peer review of the manure management practice assumptions by involving individuals with specific knowledge in disciplines associated with the parameters used to calculate factors (e.g. manure management practices and animal nutrition).
- If using the Tier 2 method, the inventory agency should provide a proper justification for country-specific emission factors via peer-reviewed documentation.

4.4 N_2O EMISSIONS FROM MANURE MANAGEMENT

4.4.1 Methodological issues

The nitrous oxide (N_2O) estimated in this section is the N_2O produced during the storage and treatment of manure before it is applied to land. The term ‘manure’ is used here collectively to include both dung and urine (i.e. the solids and the liquids) produced by livestock. 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. The term ‘manure management’[6] is used as a collective noun for all types of storage and treatment of manure. This chapter describes *good practice* for estimating N_2O emissions from manure management systems (MMS) using the method in the *IPCC Guidelines*. In the case of animals whose manure is unmanaged (i.e. animals grazing on pasture or grassland, animals that forage or are fed in paddocks, animals kept in pens around homes) the manure is not stored or treated but is deposited directly on land. This system of ‘manure management’ is referred to in the *IPCC Guidelines* as ‘pasture, range, and paddock’. 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 IPCC category ‘agricultural soils’. However, because the estimation method for pasture, range, and paddock N_2O emissions is the same as that for other systems of manure management, pasture, range, and paddock is discussed in this section of the *good practice guidance*.

4.4.1.1 CHOICE OF METHOD

The *IPCC Guidelines* method for estimating N_2O emissions from manure management entails multiplying the total amount of N excretion (from all animal species/categories) in each type of manure management system by an emission factor for that type of manure management system. Emissions are then summed over all manure management systems. The level of detail being applied to the *good practice* method for estimating N_2O emissions from manure management systems will depend upon national circumstances. The decision tree in Figure 4.4, Decision Tree for N_2O Emissions from Manure Management, describes *good practice* in adapting the methods in the *IPCC Guidelines* to country-specific circumstances.

To estimate emissions from manure management systems, the animal population must first be divided into species/categories that reflect the varying amounts of manure produced per animal as well as the manner in which the manure is handled. Detailed information on how to characterise the livestock population for this source is provided in Section 4.1.

The following five steps are required to estimate N_2O emissions from manure management systems:

(i) Collect population data from livestock population characterisation;

(ii) Determine the annual average nitrogen excretion rate per head ($Nex_{(T)}$) for each defined livestock species/category T;

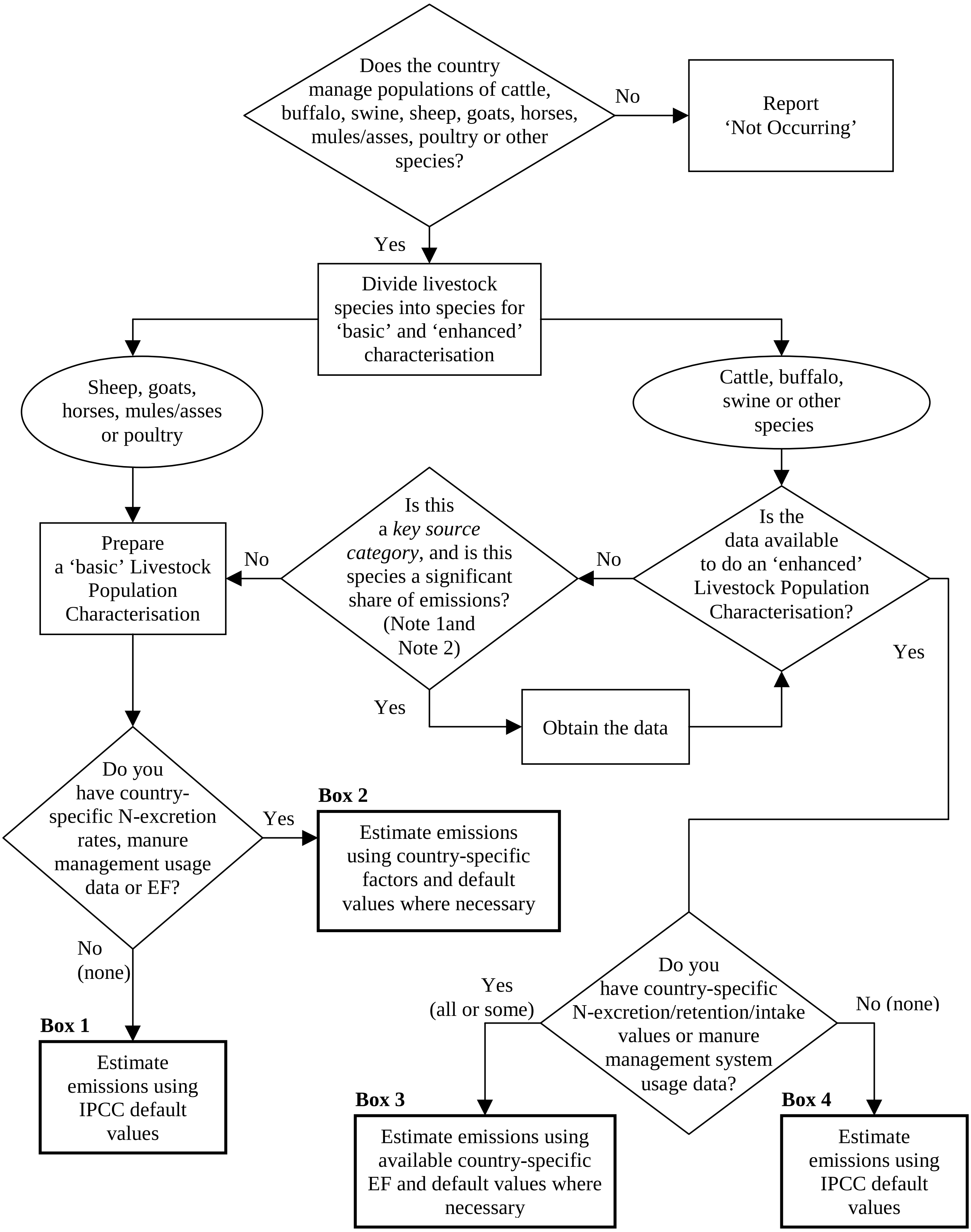
(iii) Determine the fraction of total annual excretion for each livestock species/category T that is managed in each manure management system S ($MS_{(T,S)}$);

(iv) Determine the N_2O emission factors for each manure management system S ($EF_{3(S)}$);

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

[6] Both the term ‘manure management’ and the term ‘animal waste management’ are used in the *IPCC Guidelines* to refer to animal manure that produces nitrous oxide. In this guidance, the term ‘manure management’ is used, so as to be consistent with Section 4.3 on CH_4 emissions from manure management.

Figure 4.4 Decision Tree for N_2O Emissions from Manure Management



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

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

The calculation of N_2O emissions from manure management is based on the following equation according to the *IPCC Guidelines*:

EQUATION 4.18

N_2O EMISSIONS FROM MANURE MANAGEMENT

$$(N_2O\text{-}N)_{(mm)} = \sum_{(S)} \{[\sum_{(T)} (N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)})] \bullet EF_{3(S)}\}$$

Where:

$(N_2O\text{-}N)_{(mm)}$ = N_2O-N emissions from manure management in the country (kg N_2O-N/yr)

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

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

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

$EF_{3(S)}$ = N_2O emission factor for 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

Conversion of $(N_2O\text{-}N)_{(mm)}$ emissions to $N_2O_{(mm)}$ emissions for reporting purposes is performed by using the following equation:

$$N_2O_{(mm)} = (N_2O\text{-}N)_{(mm)} \bullet 44/28$$

4.4.1.2 CHOICE OF EMISSION FACTORS

The most accurate 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. The *IPCC good practice* emission factors are presented in Table 4.12, Default Emission Factors for N_2O from Manure Management, and Table 4.13, Default Emission Factors for N_2O from Manure Management Systems not Specified in the *IPCC Guidelines*. These tables contain default emission factors, along with descriptions of the management systems, for several manure management systems that are not included in Table 4-22 of the Reference Manual of the *IPCC Guidelines*.

TABLE 4.12

DEFAULT EMISSION FACTORS FOR N_2O FROM MANURE MANAGEMENT

(ADDITIONAL SYSTEMS AND CHANGES TO THE *IPCC GUIDELINES* ARE NOTED IN ITALICS.)

System	Description	EF_3 (kg N_2O-N/kg Nitrogen excreted)	Uncertainty ranges of EF_3 [%]
Pasture/range/ paddock	*This manure is deposited directly on soils by livestock, i.e. it is unmanaged.*	0.02	-50%/ +100%
Daily Spread	*There is little or no storage or treatment of manure before it is applied to soils, so emissions during storage and treatment are assumed to be zero.*	0.0	Not Applicable
Solid storage[a]	Dung and urine (with or without litter) is collected but is stored in bulk for a long time (months) before disposal, with or without liquid runoff into a pit system.	0.02	-50%/ +100%
Dry lot	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.	0.02	-50%/ +100%
Liquid/Slurry	These systems are characterised by combined storage of dung and urine in tanks. To facilitate handling as a liquid, water may be added to the dung and urine.	0.001	-50%/ +100%
Anaerobic Lagoon	Anaerobic lagoon systems are characterised by flush systems that use water to transport manure to lagoons. The manure resides 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 fertilise fields.	*0.001*	-50%/ +100%
Open pits below animal confinements	*Combined storage of dung and urine below animal confinements.*	*0.001*	-50%/ +100%
Anaerobic Digester	*Dung and urine is anaerobically digested to produce CH_4 gas for energy.*	*0.001*	-50%/ +100%
Burned for fuel[b]	Dung is collected and dried in cakes and burned for heating or cooking. *The urine N is deposited on pasture and paddock and must be treated in that category.*	*0.007* *0.02*	-50%/ +100%

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

[b]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. Direct and indirect N_2O emissions associated with the urine deposited on agricultural soils are treated in Sections 4.7 and 4.8, respectively.

Source: *IPCC Guidelines* and Judgement by Expert Group (see Co-chairs, Editors and Experts; N_2O Emissions from Manure Management).

TABLE 4.13 **DEFAULT EMISSION FACTORS FOR N_2O FROM MANURE MANAGEMENT SYSTEMS NOT SPECIFIED IN THE *IPCC GUIDELINES* (JUDGEMENT BY EXPERT GROUP)**			
Additional Systems	**Definition**	**EF_3 (kg N_2O-N/kg nitrogen excreted)**	**Uncertainty Ranges of EF_3 (%)**
Cattle and Swine Deep Litter	Cattle/swine dung and urine are excreted on stall floor. The accumulated waste is removed after a long time.		
	<1 month	0.005	-50%/+100%
	>1 month	0.02	-50%/+100%
Composting - Intensive	Dung and urine are collected and placed in a vessel or tunnel, there is forced aeration of the waste	0.02	-50%/+100%
Composting - Extensive	Dung and urine collected, stacked and regularly turned for aeration	0.02	-50%/+100%
Poultry manure with bedding	Manure is excreted on floor with bedding. Birds walk on waste.	0.02	-50%/+100%
Poultry manure without bedding	Manure is excreted on floor without bedding. Birds do not walk on waste	0.005	-50%/+100%
Aerobic Treatment	Dung and manure is collected as a liquid. The waste undergoes forced aeration, or is treated in aerobic ponds or wetland systems to provide nitrification and denitrification.	0.02	-50%/+100%
Source: Judgement by Expert Group (see Co-chairs, Editors and Experts; N_2O Emissions from Manure Management).			

4.4.1.3 CHOICE OF ACTIVITY DATA

There are three main types of activity data for estimating N_2O emissions from manure management systems: (1) livestock population data, (2) nitrogen excretion data for each animal species/category, and (3) manure management system usage data.

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

The livestock population data should be obtained using the approach described in the Livestock Population Characterisation (see Section 4.1). If using default nitrogen excretion rates to estimate N_2O emissions from manure management systems, a 'Basic' livestock population characterisation is sufficient. To estimate N_2O emissions from manure management using calculated nitrogen excretion rates, an 'Enhanced' characterisation must be performed. As noted in Section 4.1, *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.

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

Accurate annual nitrogen excretion rates should be determined for each animal species/category defined by the livestock population characterisation. Country-specific rates may either be taken directly from documents or reports such as from the 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 utilise 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 excretion rates should be used (see Table 4-20 in the Reference Manual of the *IPCC Guidelines*). In order to adjust the values for young animals, it is *good practice* to multiply the N excretion rates in Table 4-20 by the default adjustment factors shown in Table 4.14, Default Adjustment Factors for Table 4-20 in the *IPCC Guidelines*. When estimating the $Nex_{(T)}$ for animals whose manure is classified in the manure management system *burned for fuel* (Table 4.12, Default emission factors for N_2O from Manure Management), it should be kept in mind that the dung is burned and the urine stays in the field. As a rule of thumb, 50% of the nitrogen excreted is in the dung and 50% is in the urine. Therefore, these proportions of $Nex_{(T)}$ should be multiplied by the appropriate emission factors in Table 4.12 to obtain N_2O-N emissions for these sub-source categories. If the burned dung is used as fuel, then emissions are reported under the IPCC category *fuel combustion*, whereas if the dung is burned without energy recovery the emissions should be reported under the IPCC category *waste incineration*.

TABLE 4.14

DEFAULT ADJUSTMENT FACTORS FOR TABLE 4-20 IN THE *IPCC GUIDELINES* (REFERENCE MANUAL) WHEN ESTIMATING N EXCRETION RATES FOR YOUNG ANIMALS [a]

Animal Species/Category	Age Range (years)	Adjustment Factor
Non-Dairy Cattle	0 - 1	0.3
Non-Dairy Cattle	1 - 2	0.6
Dairy Cattle	0 - 1	0.3
Dairy Cattle	1 - 2	0.6
Poultry	0 - 0.25	0.5
Sheep	0 - 1	0.5
Swine	0 - 0.5	0.5

[a] The adjustment factor is 1 when the age of the animals exceeds the indicated age range.

Note: The category termed *Other Animals* in Table 4-20 of the *IPCC Guidelines*, Reference Manual, is not provided with adjustment factors.

Source: Judgement by Expert Group (see Co-chairs, Editors and Experts; N_2O Emissions from Manure Management).

The annual amount of N excreted by each animal 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, and wool) is a measure of the animal's efficiency of production of animal protein from feed protein. Nitrogen intake and retention data for specific animal 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 the Livestock Population Characterisation Section (see Section 4.1). Default N retention values are provided in Table 4.15, 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 animal species/category ($Nex_{(T)}$) are derived as follows:

EQUATION 4.19

ANNUAL N EXCRETION RATES

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

Where:

($Nex_{(T)}$) = annual N excretion rates, kg N/animal-year

$N_{intake(T)}$ = The annual N intake per head of animal of species/category *T* , kg N/animal-year

$N_{retention(T)}$ = Fraction of annual N intake that is retained by animal of species/category *T* kg N retained/animal/year per kg N intake/animal/year

Note that annual nitrogen excretion data are also used for the calculation of direct and indirect N_2O emissions from agricultural soils (see Sections 4.7 and 4.8). The same rates of N excretion, and methods of derivation, that are used to estimate N_2O emissions from manure management should be used to estimate N_2O emissions from agricultural soils.

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

The manure management system usage data used to estimate N_2O emissions from manure management should be the same as those that are used to estimate CH_4 emissions from manure management (see Section 4.3). If country-specific manure management system usage data are not available, default values from the *IPCC Guidelines* should be used. The IPCC default values for dairy cattle, non-dairy cattle, buffalo, and swine should be taken from Tables B-3 through B-6 of Appendix B of Section 4.2 (livestock) of the Agriculture Chapter of the Reference Manual. The IPCC default values for all other animal species/categories should be taken from Table 4-21 of the Agriculture Chapter of the Reference Manual.

TABLE 4.15

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

Animal category	$N_{retention(T)}$ (kg N retained/animal/year per kg N intake/animal/year)	Uncertainty range [%]
Dairy cattle	0.2	+/-50
Non dairy cattle	0.07	+/-50
Buffalo	0.07	+/-50
Sheep	0.1	+/-50
Goats	0.1	+/-50
Camels	0.07	+/-50
Swine	0.3	+/-50
Horses	0.07	+/-50
Poultry	0.3	+/-50

Source: Judgement by Expert Group (see Co-chairs, Editors and Experts; N_2O Emissions from Manure Management).

4.4.1.4 UNCERTAINTY ASSESSMENT

Emission factors

There are large uncertainties associated with the default emission factors for this source category (see Tables 4.12 and 4.13). Accurate and well-designed emission measurements from well characterised types of manure and manure management systems can help to reduce these uncertainties. These measurements must account for temperature, moisture conditions, aeration, manure N content, metabolisable carbon, duration of storage, and other aspects of treatment.

Activity data – Livestock populations

See Section 4.1- Livestock Population Characterisation

Activity data - Nitrogen excretion rates

Uncertainty ranges for the default N excretion rates (see Table 4-20 in the *IPCC Guidelines*, Reference Manual), which are not provided in the *IPCC Guidelines*, are estimated at about +/–50% (Source: Judgement by Expert Group. See Co-chairs, Editors and Experts; N_2O Emissions from Manure Management). The uncertainty ranges for the default N retention values provided here are also +/–50% (see Table 4.15). If inventory agencies derive N excretion rates using accurate in-country statistics on N intake and N retention, the uncertainties associated with the N excretion rates may be as low as +/–25%.

Activity data – Manure management system usage

For some countries, the uncertainties associated with manure management system usage data are high. Although a well-defined classification scheme has been developed (see Tables 4.12 and 4.13), many inventory agencies only have limited, if any, quantitative data on the amounts of manure managed in different systems, beyond what is presented in Table 4-21 in the *IPCC Guidelines*, Reference Manual.

4.4.1.5 COMPLETENESS

A complete inventory should estimate N_2O emissions from all systems of manure management for all livestock species/categories. Countries are encouraged to utilise manure management definitions that are consistent with those in Tables 4.12 and 4.13. For more information regarding the completeness of livestock characterisation, see Section 4.1.

4.4.1.6 DEVELOPING A CONSISTENT TIME SERIES

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. Guidance on the development of this time series is addressed in Section 4.1. 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, or the entire livestock sector may undergo a change such that a greater fraction of manure from a certain livestock species/category is managed in wet systems rather than in dry systems, or a particular system of manure management may change 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 data and emission factors used to estimate emissions must reflect the change, and the data, methods, and results must be thoroughly documented. If activity data over a time series are affected by a change in farm practices or the implementation of greenhouse gas mitigation measures (e.g. annual N excretion rates decline due to policy measures implemented to decrease N_2O emissions through reductions in annual N intake), the inventory agency is encouraged to ensure that the activity data reflect these practices and that the inventory text thoroughly explains how the change in farm practices or implementation of mitigation measures has affected the time series of activity data or emission factors.

4.4.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. When country-specific emission factors, N excretion rates or manure management system usage data or both 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 the *IPCC Guidelines*. Referring to the *IPCC Guidelines*, 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 *agricultural soils* because this manure is deposited directly on soils by the livestock.
- Emission from the manure management system *burned for fuel*, are to be reported under the IPCC category *fuel combustion* if the dung is used as fuel and under the IPCC category *waste incineration* if the dung is burned without energy recovery. It should be noted, however, if the urine nitrogen is not collected for burning it must be reported under N_2O emissions from *pasture, range, paddock* animals.

It must be kept in mind that after 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 *agricultural soils*. The methods for estimating these emissions are discussed in Sections 4.7 and 4.8.

4.4.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to implement quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates.

Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, 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, as outlined in Chapter 8, QA/QC, could be supplemented with procedures discussed below:

Review of emission factors

- If using country-specific emission factors, the inventory agency should compare them to the default factors, and differences noted. The development of country-specific emission factors should be explained and documented, and inventory agencies are encouraged to ensure that good practice methods have been used and the results have been peer-reviewed.

Activity data check

- 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.

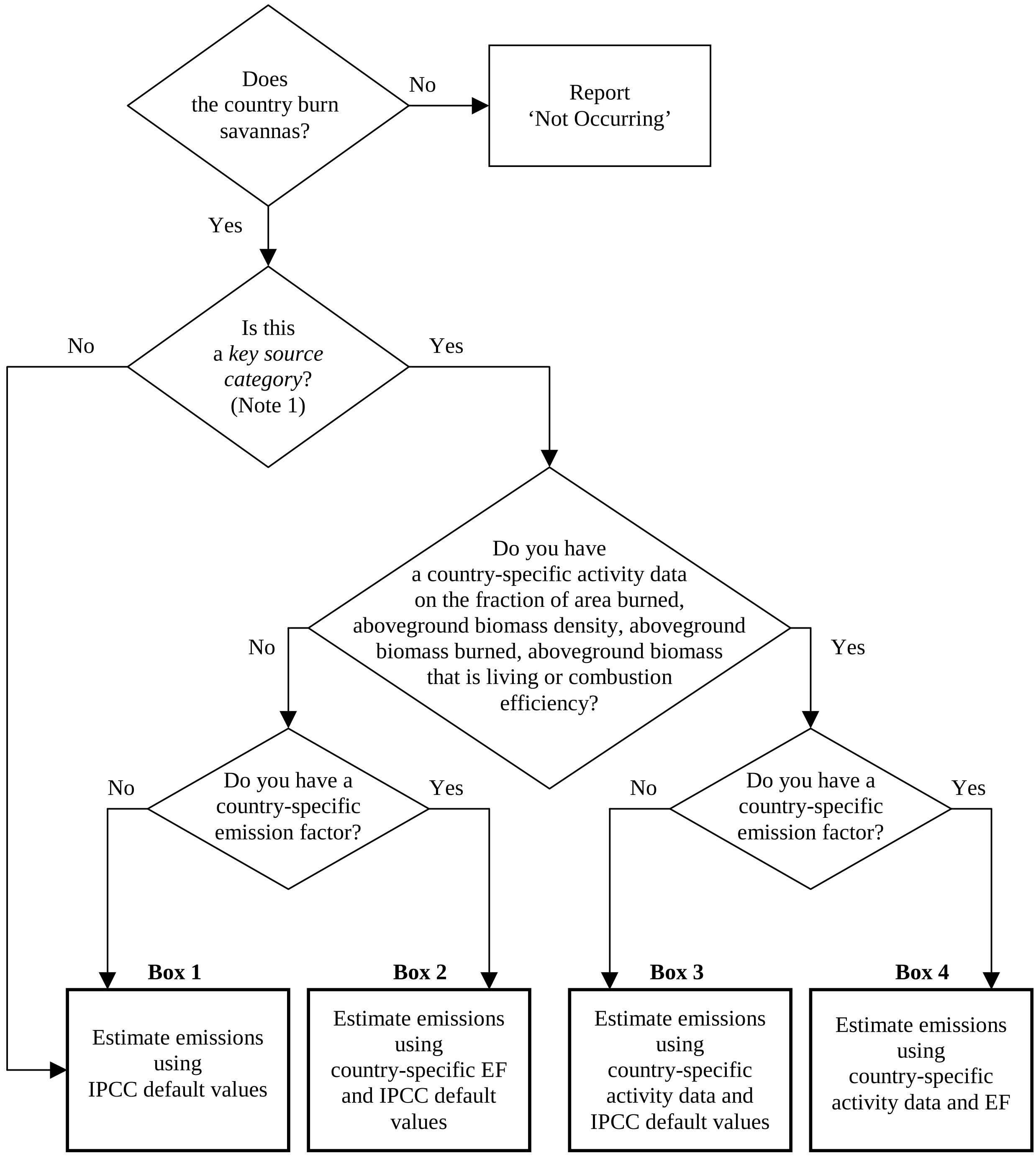
External review

- The inventory agency should utilise experts in manure management, animal nutrition, and GHG emissions to conduct expert peer review of the methods and data used.

4.5 CH_4 AND N_2O EMISSIONS FROM SAVANNA BURNING

At present, '*good practice*' for this source category is the application of the *IPCC Guidelines* following the suggested approach as set out in the decision tree in Figure 4.5, Decision Tree for CH_4 and N_2O Emissions from Savanna Burning. There is potential for further refinement of the method as indicated in Appendix 4A.1 at the end of this chapter. The appendix describes some of the details of a possible procedure for future revision of the methodology. At this time, the paucity of the data and size of uncertainties in many of the key parameters do not justify adoption of the material discussed in Appendix 4A.1 as *good practice*.

Figure 4.5 Decision Tree for CH_4 and N_2O Emissions from Savanna Burning

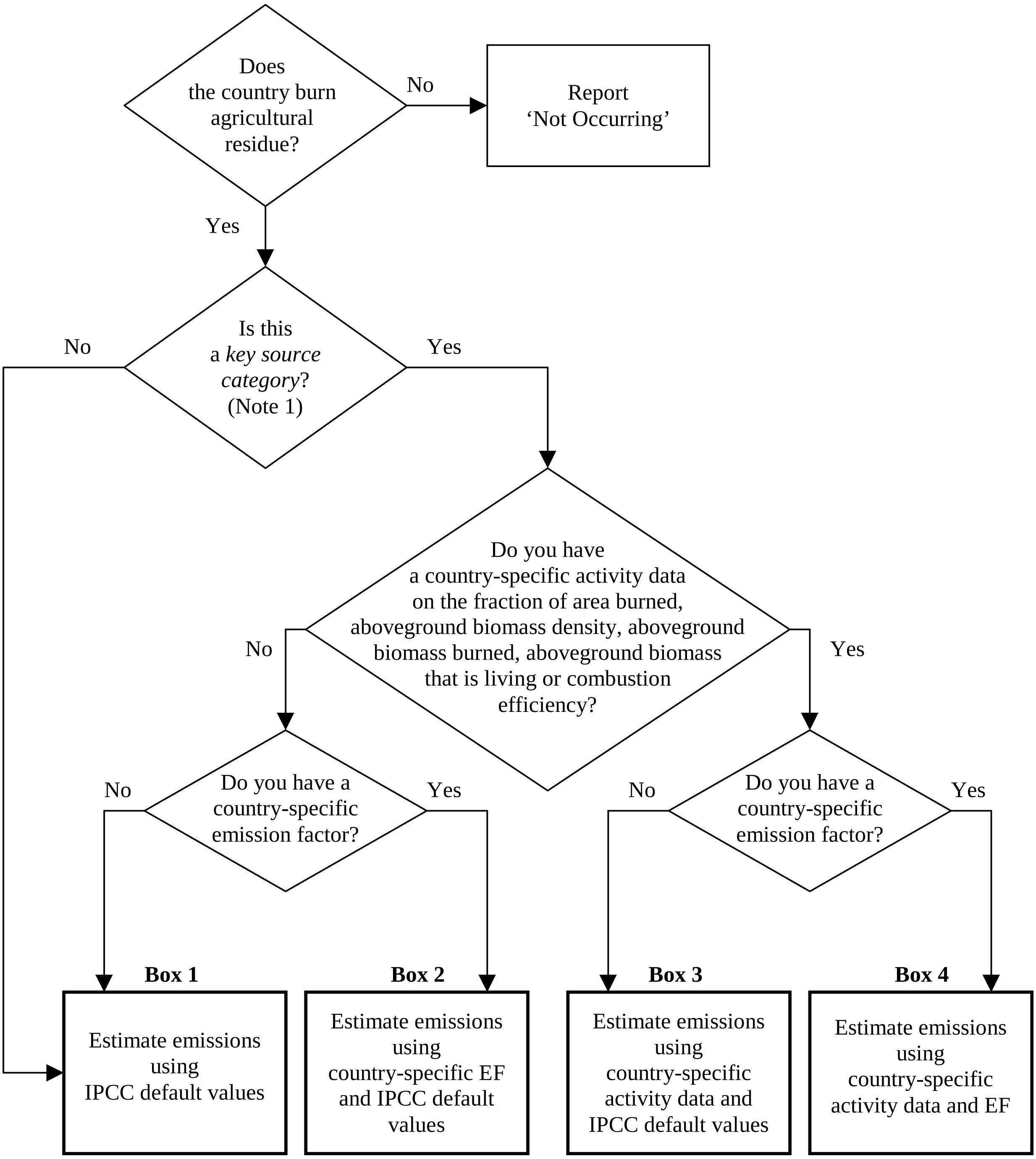


Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

4.6 CH_4 AND N_2O EMISSIONS FROM AGRICULTURAL RESIDUE BURNING

At present, '*good practice*' for this source category is the application of the *IPCC Guidelines* following the suggested approach as set out in the decision tree in Figure 4.6, Decision Tree for CH_4 and N_2O Emissions from Agricultural Residue Burning. There is potential for further refinement of the method as indicated in Appendix 4A.2 at the end of this chapter. The appendix describes some of the details of a possible procedure for future revision of the methodology. At this time, the paucity of the data and size of uncertainties in many of the key parameters do not justify adoption of the material discussed in Appendix 4A.2 as *good practice*.

Figure 4.6 Decision Tree for CH_4 and N_2O Emissions from Agricultural Residue Burning



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

4.7 DIRECT N_2O EMISSIONS FROM AGRICULTURAL SOILS

4.7.1 Methodological issues

Nitrous oxide (N_2O) is produced naturally in soils through the microbial processes of nitrification and denitrification. A number of agricultural activities add nitrogen to soils, increasing the amount of nitrogen (N) available for nitrification and denitrification, and ultimately the amount of N_2O emitted. The emissions of N_2O that result from anthropogenic N inputs occur through both a direct pathway (i.e. directly from the soils to which the N is added), and through two indirect pathways (i.e. through volatilisation as NH_3 and NO_x and subsequent redeposition, and through leaching and runoff). In the *IPCC Guidelines*, direct and indirect emissions of N_2O from agricultural soils are estimated separately.

The *IPCC Guidelines* method for estimating direct N_2O emissions from agricultural soils has two parts: (i) estimation of direct N_2O emissions due to N-inputs to soils (excluding N-inputs from animals on pasture, range, and paddock); and (ii) estimation of direct N_2O emissions from unmanaged animal manure (i.e. manure deposited by animals on pasture, range, and paddock).[7] This section discusses the first part of this method. The second part, estimation of direct N_2O emissions from pasture, range, and paddock manure, is covered in Section 4.4: N_2O Emissions from Manure Management.[8] Note, however, that direct N_2O emissions from pasture, range and paddock manure are to be reported in the agricultural soil category.

4.7.1.1 CHOICE OF METHOD

The approach described in the *IPCC Guidelines* for estimating direct N_2O emissions from agricultural soils due to applications of N and other cropping practices accounts for anthropogenic nitrogen (N) inputs from the application of: synthetic fertilisers (F_{SN}) and animal manure (F_{AM}); the cultivation of N-fixing crops (F_{BN}); incorporation of crop residues into soils (F_{CR}); and soil nitrogen mineralisation due to cultivation of organic soils[9] (i.e. histosols) (F_{OS}).[10] As the *IPCC Guidelines* treat indirect and direct emissions separately, the portion of applied synthetic fertiliser and animal manure N that volatilises after application is subtracted from the amounts applied, and the N_2O that is eventually emitted from this volatilised N is included as part of the indirect emissions (see Section 4.8).

The terms Tier 1a and Tier 1b have been used throughout the *IPCC Report on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (*Good Practice Report),* Subsections 4.7 and 4.8, to differentiate between the equations in the *IPCC Guidelines* (Tier 1a) and new equations (Tier 1b) presented here. The Tier 1b equations represent increased precision due to expansion of the terms in the equations. However, while Tier 1b equations may be preferred, the activity data needed to use them may not be available. In these cases, use of Tier 1a equations is appropriate. Estimating emissions using a combination of Tier 1a and Tier 1b equations for different sub-source categories, depending upon availability of activity data, is also acceptable. In some cases, there is no Tier 1b alternative because no refinement of the equation in the *IPCC Guidelines* was considered necessary.

The decision tree, Figure 4.7, Decision Tree for Direct N_2O Emissions from Agricultural Soils describes g*ood practice* in adapting the methods in the *IPCC Guidelines* to country-specific circumstances. The decision tree

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[7] As in Section 4.4, the term ‘manure’ is used here collectively to include both dung and urine.

[8] Even though animal manure deposited on pasture, range, and paddock is not managed, it is addressed in Section 4.4, because the method for estimating emissions from pasture, range, and paddock manure is the same as the method for estimating emissions from manure management systems.

[9] Organic soils are soils described as Histosols which are defined as: ‘Organic soils that have organic soil materials in more than half of the upper 80 cm, or that are of any thickness of overlying rock or fragmented materials that have interstices filled with organic soil materials.’ An organic soil material is defined as: ‘soil materials that are saturated with water and have 174 g kg^{-1} or more organic carbon if the mineral fraction has 500 g kg^{-1} or more clay, or 116 g kg^{-1} organic carbon if the mineral fraction has no clay, or has proportional intermediate contents, or if never saturated with water, have 203 g kg^{-1} or more organic carbon (SSSA, 1996).

[10] Histosols are soils containing an organic-rich surface layer at least 40 cm in thickness, with a minimum of 20% organic matter if the clay content is low, and a minimum of 30% organic matter where the clay content exceeds 50%.

describes how to choose the method of estimation. Both Tier 1a and Tier 1b are consistent with good practice, provided the emission factors and activity data are developed according to the guidance presented below.

In its most basic form, direct N_2O emissions from agricultural soils are estimated as follows:

EQUATION 4.20

DIRECT N_2O EMISSIONS FROM AGRICULTURAL SOILS (TIER 1a)

$$N_2O_{Direct}\text{-}N = [(F_{SN} + F_{AM} + F_{BN} + F_{CR}) \bullet EF_1] + (F_{OS} \bullet EF_2)$$

Where:

N_2O_{Direct}-N = Emission of N_2O in units of Nitrogen

F_{SN} = Annual amount of synthetic fertiliser nitrogen applied to soils adjusted to account for the amount that volatilises as NH_3 and NO_x

F_{AM} = Annual amount of animal manure nitrogen intentionally applied to soils adjusted to account for the amount that volatilises as NH_3 and NO_x

F_{BN} = Amount of nitrogen fixed by N-fixing crops cultivated annually

F_{CR} = Amount of nitrogen in crop residues returned to soils annually

F_{OS} = Area of organic soils cultivated annually

EF_1 = Emission factor for emissions from N inputs (kg N_2O-N/kg N input)

EF_2 = Emission factor for emissions from organic soil cultivation (kg N_2O-N/ha-yr)

Conversion of N_2O-N emissions to N_2O emissions for reporting purposes is performed by using the following equation:

$$N_2O = N_2O\text{-}N \bullet 44/28$$

The use of Equation 4.20 is considered Tier 1a. If more detailed emission factors are available to a country, further disaggregation of the terms in the equation can be undertaken, as shown in Equation 4.21 which is the Tier 1b equation. For example, if emission factors are available for the application of synthetic fertilisers and animal manure (F_{SN} and F_{AM}) under different conditions *i*, Equation 4.20 would be expanded as:

EQUATION 4.21

DIRECT N_2O EMISSIONS FROM AGRICULTURAL SOILS (TIER 1b)

$$N_2O_{Direct}\text{-}N = \sum_i \{[(F_{SN} + F_{AM})_i \bullet EF_i] + [(F_{BN} + F_{CR}) \bullet EF_1] + [F_{OS} \bullet EF_2]\}$$

Where:

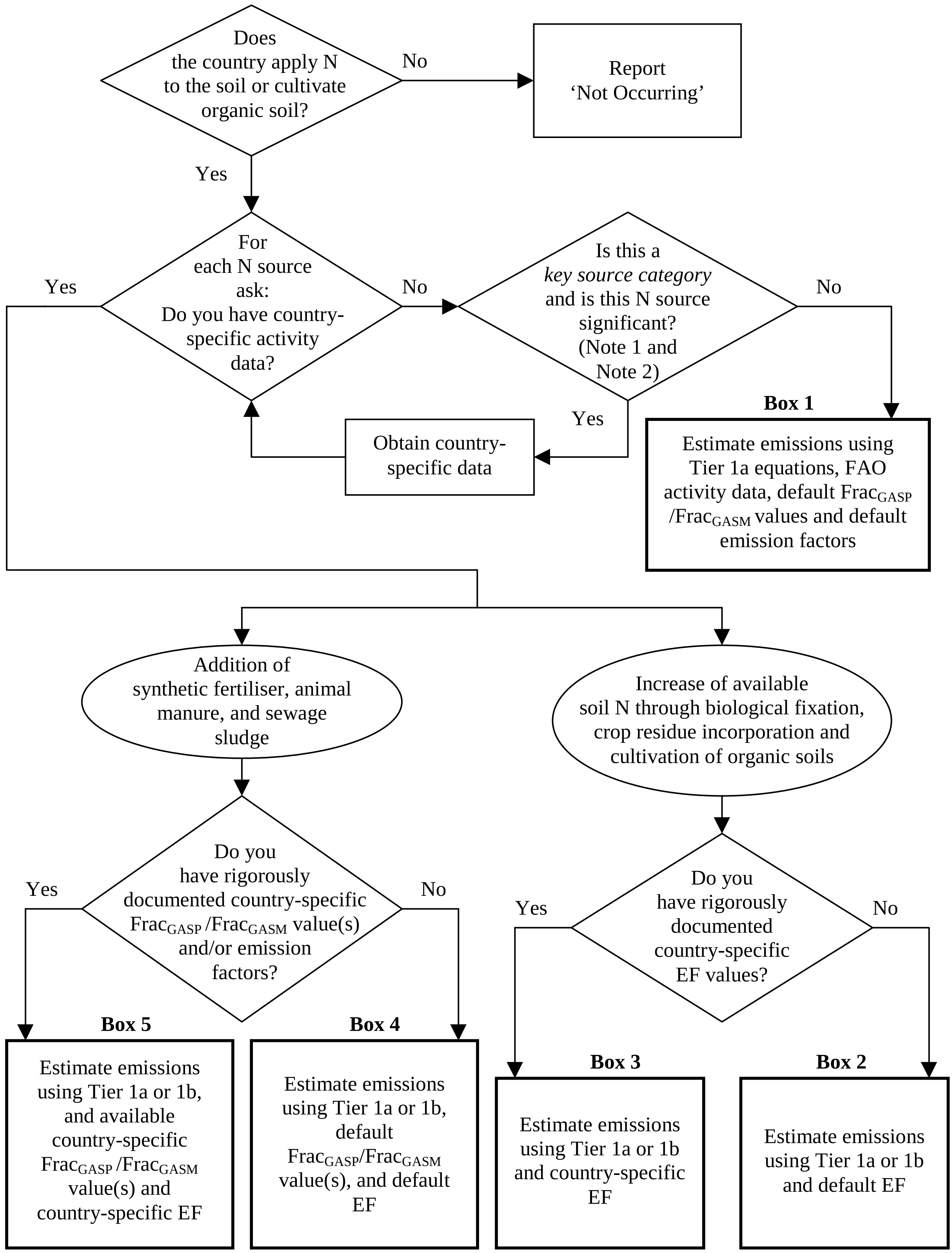
EF_i = Emission factors developed for N_2O emissions from synthetic fertiliser and animal manure application under different conditions *i*.

Conversion of N_2O-N emissions to N_2O emissions for reporting purposes is performed by using the following equation:

$$N_2O = N_2O\text{-}N \bullet 44/28$$

The Tier 1a approach can also be expanded to include other forms of N applied to all types of soils. For example, sewage sludge, an additional form of organic N, is often applied to soils as a soil amendment or dispose of the sludge. Sewage sludge nitrogen ($N_{SEWSLUDGE}$) can be included in this calculation if sufficient information is available. The sludge input should be measured in units of N and multiplied by EF_1 (i.e. in Equation 4.20, $N_{SEWSLUDGE}$ should be added to the first set of parentheses in Equation 4.21, it should be added inside the second set of parentheses).

Figure 4.7 Decision Tree for Direct N_2O Emissions from Agricultural Soils



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

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

Note that there are no default data for the new parameter $N_{SEWSLUDGE}$, or guidance on collecting such data. Therefore, this refinement should only be used if reliable country-specific data are available. The sewage sludge activity data used to estimate direct N_2O emissions should be the same as those used to estimate indirect N_2O emissions (see Section 4.8, Indirect N_2O Emissions from Nitrogen Used in Agriculture).

In order to apply either Equation 4.20 or 4.21, the amounts of various N inputs (F_{SN}, F_{AM}, F_{BN}, F_{CR}, F_{OS}) must be estimated. The *IPCC Guidelines* describe methods for how such calculations are to be made. In some cases, refinements in these methods are suggested for *good practice* in order to correct errors, ensure consistency between this source category and other agricultural source categories, and incorporate new information that has become available since the *IPCC Guidelines* were written. In addition, for some N inputs, detailed equations that describe how to implement the more disaggregated approaches are presented. Using a mix of aggregated and disaggregated equations to calculate the various N inputs is consistent with *good practice* in the derivation of each term in Equations 4.20 and 4.21 as described below.

Synthetic Fertiliser Nitrogen, Adjusted for Volatilisation (F_{SN}): The term $\underline{F_{SN}}$ refers to the annual amount of synthetic fertiliser nitrogen applied to soils after adjusting to account for the amount that volatilises. It is estimated by determining the total amount of synthetic fertiliser consumed annually (N_{FERT}), and then adjusting this amount by the fraction that volatilises as NH_3 and NO_x ($Frac_{GASF}$). The equation is thus:

EQUATION 4.22

N FROM SYNTHETIC FERTILISER APPLICATION

$$F_{SN} = N_{FERT} \bullet (1 - Frac_{GASF})$$

Animal Manure Nitrogen Used as Fertiliser, Adjusted for Volatilisation (F_{AM}): The term $\underline{F_{AM}}$ refers to the amount of animal manure nitrogen intentionally applied to soils after adjusting to account for the amount that volatilises. It is estimated by determining the total amount of animal manure nitrogen produced annually ($\sum_T(N_{(T)} \bullet Nex_{(T)})$) [11], and then adjusting this amount to account for the animal manure that is burned for fuel ($Frac_{FUEL-AM}$)[12], deposited onto soils by grazing livestock ($Frac_{PRP}$) and volatilised as NH_3 and NO_x ($Frac_{GASM}$). For this calculation, the equation presented in the *IPCC Guidelines* is replaced by:

EQUATION 4.23

N FROM ANIMAL MANURE APPLICATION

$$F_{AM} = \sum_T(N_{(T)} \bullet Nex_{(T)}) \bullet (1 - Frac_{GASM})[1 - (Frac_{FUEL-AM} + Frac_{PRP})]$$

Equation 4.23, however, may not be complete for all countries because animal manure may be used in ways other than as fuel. Since some countries use some of their animal manure for animal feed and for construction, a complete assessment should also determine the fractions of the animal manure (if any) that are used in this way ($Frac_{FEED-AM}$ and $Frac_{CNST-AM}$, respectively). Tier 1b can account for these uses and avoid overestimating emissions. It is assumed that all animal manure not used for another purpose will be applied to soils. The suggested *good practice* Tier 1b equation is thus:

EQUATION 4.24

N FROM ANIMAL MANURE APPLICATION (EXPANDED)

$$F_{AM} = \sum_T(N_{(T)} \bullet Nex_{(T)}) \bullet (1 - Frac_{GASM}) \bullet [1 - (Frac_{FUEL-AM} + Frac_{PRP} + Frac_{FEED-AM} + Frac_{CNST-AM})]$$

Note, however, that if the term $Frac_{PRP}$ includes fractions of animal manure used as fuel, feed, or construction, then whichever fractions are included in $Frac_{PRP}$ should not be included in Equation 4.24.

[11] In this part of the *IPCC Guidelines*, the variable Nex is used for the total amount of animal manure produced. To be consistent with *good practice* in Section 4.4, this variable name has been revised to $\Sigma_T(N_{(T)} \bullet Nex_{(T)})$.

[12] In equations 4.23 and 4.24, the term used in the *IPCC Guidelines* ($Frac_{FUEL}$), has been renamed $Frac_{FUEL-AM}$, so as to distinguish it from the fraction of crops used as fuel ($Frac_{FUEL-CR}$) in Equation 4.29.

N fixed by Crops (F_{BN}): The approach presented in the *IPCC Guidelines* for estimating the amount of nitrogen fixed by N-fixing crops cultivated annually ($\underline{F_{BN}}$) is based on the assumption that the amount of N contained in the aboveground plant material (crop product plus residues) is a reasonable proxy for the total amount of N fixed by the crop. The *IPCC Guidelines* also assumes that the mass ratio of residue to product is 1 (i.e. the total aboveground plant biomass is 2 times the crop product). Therefore, the amount of fixed N is estimated by multiplying the seed yield of pulses and soybeans ($Crop_{BF}$) by a default value of 2 and then by the fraction of crop biomass that is nitrogen ($Frac_{NCRBF}$). The Tier 1a equation presented in the *IPCC Guidelines* is thus:

EQUATION 4.25

N FIXED BY CROPS (TIER 1A)

$$F_{BN} = 2 \bullet Crop_{BF} \bullet Frac_{NCRBF}$$

The approach suggested in the *IPCC Guidelines* can be modified in several ways to estimate more accurately the total mass of aboveground crop residue and product nitrogen. For example, Equation 4.25 uses a default value of 2 to convert $Crop_{BF}$ to total aboveground crop residue and product. This factor is too low for some pulses and soybeans, and may result in underestimating the total aboveground crop residue and product (see Table 4.16, Selected Crop Residue Statistics). As the ratio of aboveground biomass to crop product mass varies among crop types, more accurate estimates can be developed if crop specific values are used. Dry matter fractions also need to be incorporated into the equation so that adjustments are made for moisture contents. In addition, $Crop_{BF}$ should be defined so that it is representative of the products of all N-fixing crops, not just the seed yield of pulses and soybeans. In particular, N-fixing forage crops such as alfalfa should be included in the calculations. The approach is shown in Equation 4.26:

EQUATION 4.26

N FIXED BY CROPS (TIER 1b)

$$F_{BN} = \sum_i [Crop_{BF_i} \bullet (1 + Res_{BF_i}/Crop_{BF_i}) \bullet Frac_{DM_i} \bullet Frac_{NCRBF_i}]$$

Equation 4.26 introduces two new terms. The first, $Res_{BF_i}/Crop_{BF_i}$, represents the residue to crop product mass ratio specific to each crop type *i* (see Table 4.16). The second, $Frac_{DM_i}$, is the fraction of dry matter in the aboveground biomass of each crop type *i*. The term $[(1 + Res_{BF_i}/Crop_{BF_i}) \bullet Frac_{DM_i}]$ replaces the default value of '2' presented in the *IPCC Guidelines.* Note that it is assumed that the dry matter content of the residue and product are equal so only one dry matter variable is included in the equation. Countries may have dry matter contents specific to the product and the residue – these should be used if the additional effort is warranted by increased accuracy. Additionally, the variable $Crop_{BF}$ as currently defined in the *IPCC Guidelines* is the seed yield of pulses + soybeans in a country. However, this does not take into account crops such as alfalfa where the entire plant is harvested as product. Therefore, as mentioned above, $Crop_{BF}$ should be defined as the 'production of N-fixing crops.' In the case of N-fixing forage crops such as alfalfa, $Res_{BF_i}/Crop_{BF_i}$ will equal 0, and the equation 4.26 becomes:

EQUATION 4.27

N FIXED BY N-FIXING FORAGE CROPS

$$F_{BN} = \sum_i (Crop_{BF_i} \bullet Frac_{DM_i} \bullet Frac_{NCRBF_i})$$

Note that if inventory agencies use Equation 4.26 to estimate the amount of N fixed by N-fixing crops, and if any of the residues of these crops are burned in the field, they should use the same values for $Crop_{BF}$, $Res_{BF_i}/Crop_{BF_i}$, and $Frac_{DM_i}$ that are used in estimating emissions from agricultural residue burning. The values used for $Frac_{NCRBF_i}$ should also be consistent with N/C ratios used in estimating emissions from agricultural residue burning. *Good practice* default values for $Res_{BF_i}/Crop_{BF_i}$, $Frac_{DM_i}$, and $Frac_{NCRBF_i}$, for some crop types, are presented in Table 4.16. Inventory agencies may use these values if country-specific data are not available. If a default residue nitrogen content is needed for a crop type for which a value is not provided in Table 4.16, the non-crop specific default value listed in Table 4-19 of the Reference Manual of the *IPCC Guidelines* (0.03 kg N/kg dry matter) can be used.

TABLE 4.16				
SELECTED CROP RESIDUE STATISTICS				
Product	**Residue/Crop Product Ratio**	**Dry Matter Fraction**	**Carbon Fraction**	**Nitrogen Fraction**
Wheat	1.3	0.82-0.88	0.4853	0.0028
Barley	1.2	0.82-0.88	0.4567	0.0043
Maize	1.0	0.70-0.86	0.4709	0.0081
Oats	1.3	0.92		0.0070
Rye	1.6	0.90		0.0048
Rice	1.4	0.82-0.88	0.4144	0.0067
Millet	1.4	0.85-0.92		0.0070
Sorghum	1.4	0.91		0.0108
Peas	1.5	0.87		0.0142
Beans	2.1	0.82-0.89		
Soybeans	2.1	0.84-0.89		0.0230
Potatoes	0.4		0.4226	0.0110
Feedbeet	0.3		0.4072[a]	0.0228[a]
Sugarcane tops		0.32	0.4235	0.0040
Sugarcane leaves		0.83	0.4235	0.0040
Jerusalem artichoke	0.8			
Peanuts	1.0	0.86		0.0106

[a] These figures are for beet leaves.

Source: All data from Strehler and Stützle (1987), except sugarcane data (Turn *et al.*, 1997), dry matter and nitrogen fraction data for oats, rye, sorghum, peas, and peanuts (Cornell, 1994), and nitrogen fraction data for millet and soybeans (Barnard and Kristoferson, 1985).

N in Crop Residues Returned to Soils (F_{CR}): In the *IPCC Guidelines*, the amount of nitrogen returned to soils annually through incorporation of crop residues (F_{CR}) is estimated by determining the total amount of crop residue N produced (from both non-nitrogen-fixing crops and N-fixing crops), and adjusting it for the fraction that is burned in the field when residues are burned during or after harvest. The annual production of residue N is estimated by multiplying annual crop production of N-fixing crops ($Crop_{BF}$) and other crops ($Crop_O$) by their respective N contents ($Frac_{NCRBF}$ and $Frac_{NCRO}$), summing these two nitrogen values, multiplying by a default value of 2 (to yield total aboveground crop biomass), and then adjusting for the amount of total aboveground crop biomass that is removed from the field as product ($Frac_R$)[13] and burned ($Frac_{BURN}$). The Tier 1a equation presented in the *IPCC Guidelines* is thus:

EQUATION 4.28

N IN CROP RESIDUE RETURNED TO SOILS (TIER 1a)

$$F_{CR} = 2 \bullet (Crop_O \bullet Frac_{NCRO} + Crop_{BF} \bullet Frac_{NCRBF}) \bullet (1 - Frac_R) \bullet (1 - Frac_{BURN})$$

The Tier 1a approach can be modified in several ways to estimate more accurately the amount of crop residue nitrogen that is incorporated into soils:

- First, Equation 4.28 uses a default value of 2 to convert $Crop_O$ and $Crop_{BF}$ to total aboveground crop residue and product. As previously mentioned with F_{BN}, this factor is too low for some pulses and soybeans, and

[13] The *IPCC Guidelines* define $Frac_R$ as the ‘fraction of crop residue that is removed from the field as crop.’ However, this variable, as it is currently used, is instead the ‘fraction of total *aboveground crop biomass* that is removed from the field as crop.’

may result in underestimating the total aboveground crop residue and product. In addition, this factor of 2 is inconsistent with the default value for $Frac_R$ presented in the *IPCC Guidelines.* [14]

- Second, $Crop_{BF}$ should be defined so that it is representative of the products of all N-fixing crops, not just seed yield of pulses and soybeans.
- Third, dry matter fractions need to be incorporated into the equation so that adjustments are made for moisture contents.
- Fourth, the equation should be modified to account for additional uses of crop residues, specifically as fuel, construction material, and fodder. These modifications are shown in Equation 4.29:

EQUATION 4.29

N IN CROP RESIDUE RETURNED TO SOILS (TIER 1b)

$$F_{CR} = \sum_i [(Crop_{O_i} \bullet Res_{O_i}/Crop_{O_i} \bullet Frac_{DM_i} \bullet Frac_{NCRO_i}) \bullet (1 - Frac_{BURN_i} - Frac_{FUEL\text{-}CR_i} - Frac_{CNST\text{-}CR_i} - Frac_{FOD_i})] + \sum_j [(Crop_{BF_j} \bullet Res_{BF_j}/Crop_{BF_j} \bullet Frac_{DM_j} \bullet Frac_{NCRBF_j}) \bullet (1 - Frac_{BURN_j} - Frac_{FUEL\text{-}CR_j} - Frac_{CNST\text{-}CR_j} - Frac_{FOD_j})]$$

Equation 4.29 allows for available crop-specific values to be used for the following variables (i.e. each other crop type *i* and each nitrogen-fixing crop type *j*): (i) the residue to crop product mass ratio ($Res_{O_i}/Crop_{O_i}$ and $Res_{BF_j}/Crop_{BF_j}$); (ii) the dry matter content of the aboveground biomass ($Frac_{DM_i}$ and $Frac_{DM_j}$); (iii) the nitrogen content of the aboveground biomass ($Frac_{NCRO_i}$ and $Frac_{NCRBF_j}$); (iv) the fraction of residue burned in the field before and after harvest ($Frac_{BURN_i}$ and $Frac_{BURN_j}$); (v) the fraction of residue used as fuel ($Frac_{FUEL\text{-}CR_i}$ and $Frac_{FUEL\text{-}CR_j}$); (vi) the fraction of residue used for construction ($Frac_{CNST\text{-}CR_i}$ and $Frac_{CNST\text{-}CR_j}$); and (vii) the fraction of residue used as fodder ($Frac_{FOD_i}$ and $Frac_{FOD_j}$). *Good practice* default values for $Res_{O_i}/Crop_{O_i}$, $Frac_{DM_i}$, and $Frac_{NCRO_i}$, for some crop types, are presented in Table 4.16. Inventory agencies may use these values if country-specific data are not available. If a default residue nitrogen content is needed for a crop type for which a value is not provided in Table 4.16, the non-crop specific default values for N-fixing and Non-N-fixing crops that are listed in Table 4-19 of the Reference Manual of the *IPCC Guidelines* can be used (0.03 and 0.015 kg N/kg dry matter, respectively).

Area of organic soils harvested (F_{OS}): The *IPCC Guidelines* defines F_{OS} as the area (in hectares) of organic soils cultivated annually. This definition is applicable for both the Tier 1a and Tier 1b methods.

4.7.1.2 CHOICE OF EMISSION FACTORS

Two emission factors are needed to estimate direct N_2O emissions from agricultural soils. The first (EF_1) indicates the amount of N_2O emitted from the various nitrogen additions to soils, and the second (EF_2) estimates the amount of N_2O emitted from cultivation of organic soils.

Country-specific emission factors should be used where possible, in order to reflect the specific conditions of a country and the agricultural practices involved. Such emission factors should be based on measurements that are conducted frequently enough and over a long enough time period to reflect the variability of the underlying biogeochemical processes, given the selected measurement technique, and documented in refereed publications. *Good practice* in the derivation of country-specific emission factors is described in Box 4.1.

If country-specific emission factors are not available, emission factors from other countries with comparable management and climatic conditions are good alternatives. If this is not a key source category (see Chapter 7, Methodological Choice and Recalculation) or if the necessary resources are not available for deriving country- or region-specific emission factors, default emission factors may be used. It is anticipated that some inventory agencies will use a mix of default values and country-specific emission factors when the latter do not cover the

[14] The *IPCC Guidelines* present a default value for $Frac_R$ of 0.45 that is not consistent with the default value presented for aboveground crop residue and product. If $Frac_R$ = 0.45, then 55% of the residue plus crop product mass equals residue. However, if residue plus crop product mass equals 2 times the crop product, then 50% of the residue plus crop product mass equals residue.

full range of environmental and management conditions. If country-specific or other emission factors are used instead of defaults, their derivation must be clearly documented.

The *good practice* default emission factors are summarised in Table 4.17, Updated Default Emission Factors to Estimate Direct N2O Emissions from Agricultural Soils. The default value for EF_1 in the *IPCC Guidelines* is 1.25% of the nitrogen applied to soils. In many cases, this factor will be adequate. However, if synthetic fertilisers are applied to fields that are already receiving applications of organic manure, recent data indicate that higher N_2O losses may occur (Clayton *et al.*, 1997). At this time no recommendation to change the default is made because of the need for further corroborating evidence. Where this correction is needed, *good practice* requires use of a more detailed form of the basic equation presented in the *IPCC Guidelines* to ensure that the appropriate emission factors are applied to the various nitrogen inputs.

The default value for EF_2 presented in the *IPCC Guidelines* should be updated based on the results of more recent measurements. These measurements indicate that the emission factors for organic soils in mid-latitudes are higher than previously estimated (Klemedtsson *et al.*, 1999). These data suggest that a value of 8 rather than 5 is appropriate for EF_2 in mid-latitudes. Consistent with the approach taken in the *IPCC Guidelines*, in which mineralisation rates are assumed to be about 2 times greater in tropical climates than in temperate climates, the emission factor EF_2 for tropical climates should be 16.

TABLE 4.17
UPDATED DEFAULT EMISSION FACTORS TO ESTIMATE DIRECT N_2O EMISSIONS FROM AGRICULTURAL SOILS

Emission Factor	IPCC Default Value (EF_1 in kg N_2O-N/kg N) (EF_2 in kg N_2O-N/ha-yr)	Updated Default Value (EF_1 in kg N_2O-N/kg N) (EF_2 in kg N_2O-N/ha-yr)
EF_1 for F_{SN}	1.25%	No Change
EF_1 for F_{SN} when applied to fields already receiving organic fertiliser/animal manure (applied or grazing)	1.25%	No Change
EF_1 for F_{AM}	1.25%	No Change
EF_1 for F_{BN}	1.25%	No Change
EF_1 for F_{CR}	1.25%	No Change
EF_2 for Mid-Latitude Organic Soils	5	8
EF_2 for Tropical Organic Soils	10	16

Source: *IPCC Guidelines*, Klemedtsson *et al.* (1999), Clayton *et al.* (1997).

4.7.1.3 CHOICE OF ACTIVITY DATA

Several types of activity data are required to estimate direct N_2O emissions from soils. For the anthropogenic N inputs from application of synthetic fertilisers (F_{SN}) and animal manure (F_{AM}), as well as biological N-fixation by crops (F_{BN}), mineralisation of crop residues returned to soils (F_{CR}), and soil nitrogen mineralisation due to cultivation of organic soils (F_{OS}), the types and sources of the activity data and key considerations related to the application of more detailed country-and potentially crop-specific methods (now or in the future) are described below. Even if inventory agencies cannot currently prepare estimates based on country- or crop-specific emission factors , it is *good practice* to collect detailed activity data as far as possible. This will allow for a more accurate future revision of previously constructed inventories should country- or crop-specific emission factors become available.

F_{SN}: The inputs required for calculation of F_{SN} are N_{FERT} and $Frac_{GASF}$.

- Synthetic fertiliser consumption (N_{FERT}) data should be collected from official statistics (e.g. national bureaux of statistics) using yearly census data. Most inventory agencies may be able to readily obtain such data. If country-specific data are not available, data from the International Fertiliser Industry Association (IFA, Paris; www.fertiliser.org/stats.htm) on total fertiliser use by type and by crop, or from the Food and Agriculture Organisation of the United Nations (FAO; www.apps.fao.org) on synthetic fertiliser consumption can be used. It may be useful to compare national statistics to international databases such as those of the IFA and FAO. If possible, N_{FERT} data should be disaggregated by fertiliser type, crop type and climatic regime for major crops, if sufficient data are available.

- For the fraction of nitrogen that volatilises as NH_3 and NO_x from applied synthetic fertilisers ($Frac_{GASF}$), a fixed loss rate of 10% can be used in the (*IPCC Guidelines*, Table 4-19, Reference Manual). However, the loss rate can be highly variable, and depends on the type of synthetic fertiliser applied, the mode of application, and climate. The use of appropriately documented country-specific loss rates is encouraged.

F_{AM}: *Good practice* in developing the inputs for the calculation of F_{AM} using either the Tier 1a or Tier 1b equation has been summarised above. Regardless of how F_{AM} is estimated, it is suggested that the amount of animal manure applied and areas covered be disaggregated by crop type and climatic region if possible. This data may be useful in developing revised emission estimates if inventory methods are improved in the future.

- The total amount of nitrogen excreted by a country's animal population ($\Sigma_T(N_{(T)} \bullet Nex_{(T)})$) is calculated by determining the number of animals within a country by animal species/category ($N_{(T)}$) and multiplying by N excretion rates for each animal species/category ($Nex_{(T)}$). For *good practice*, the livestock population data should be developed following the approach described in Section 4.1, Livestock Population Characterisation, and must be consistent with the livestock characterisations used for other emission source categories. The N excretion rates for each animal species/category must also be consistent across source categories. The good practice approach for developing country-specific nitrogen excretion rates is described in Section 4.4: Estimating N_2O Emissions from Manure Management. If country-specific $\Sigma_T(N_{(T)} \bullet Nex_{(T)})$ rates are not available, default values from Table 4-20 in the *IPCC Guidelines* Reference Manual should be used.
- For the fraction of nitrogen that volatilises as NH_3 and NO_x from animal manure ($Frac_{GASM}$), a fixed loss rate of 20% is reported in the *IPCC Guidelines* Reference Manual Table 4-19. These losses are highly variable and depend on the type of animal manure, its storage, mode of application, and climate. Country-specific $Frac_{GASM}$ factors are encouraged for use if appropriately documented.
- The amounts of animal manure used for purposes other than fertiliser (represented by $Frac_{FUEL-AM}$, $Frac_{PRP}$, and if using the Tier 1b equation, $Frac_{CNST-AM}$ $Frac_{FEED-AM}$) can be obtained from official statistics or a survey of experts. The $Frac_{PRP}$ value used in this calculation must be consistent with the value used in calculating the N_2O emissions from grazing animals in the manure management section.

BOX 4.1
GOOD PRACTICE IN DERIVATION OF COUNTRY-SPECIFIC EMISSION FACTORS

In general, *good practice* requires the measurement of emissions by individual sub-source category (i.e. synthetic fertiliser (F_{SN}), animal manure (F_{AM}), biological N-fixation (F_{BN}), crop residue mineralisation (F_{CR}) and cultivation of organic soils (F_{OS})). For emission factors to be representative of environmental and management conditions within the country, measurements should be made in the major crop growing regions within a country, in all seasons, and if relevant, in different geographic and soil regions and under different management regimes. Appropriate selection of regions or regimes may enable a reduction in the number of sites that must be sampled to derive a reliable flux estimate. Maps or remote sensing data can provide a useful basis for delineation by utilising the variability of a system or landscape. Aggregation errors may occur if available measurements do not cover the actual range of environmental and soil management conditions, and inter-annual climatic variability. Validated, calibrated, and well-documented simulation models may be a useful tool to develop area-average emission factors on the basis of measurement data (Smith *et al.*, 1999).

Regarding measurement period and frequency, emission measurements should be taken over an entire year (including fallow periods), and preferably over a series of years, in order to reflect differences in weather conditions and inter-annual climatic variability. Measurements should be taken at least once per day following major disturbances that would cause emissions to increase above background levels (e.g. during and after rainfall events, ploughing, or fertiliser application). Less frequent measurements (once per day or less) are acceptable during periods when emissions are close to background levels. A good description of the measurement techniques that are available can be found in IAEA (1992).

To ensure accurate emission factors, it is *good practice* to monitor on representative sites those factors that may influence inter-annual variability of N_2O emissions. Such factors include fertiliser application, the previous crop, soil texture and drainage condition, soil temperature, and soil moisture. A complete list of factors that are involved in the regulation of N_2O formation, consumption, and exchange between soil and air can be found in Firestone and Davidson (1989). For N_2O emissions from organic soil cultivation, it can be assumed that the frequency of measurement need not be more detailed than that for mineral soils. The frequency of measurement should be consistent with the frequency of the disturbance event. Emissions are likely to be variable among geographic regions, especially among different cropping systems.

It is possible that N deposition from industrial sources might result in unrepresentative emission factors, but this is probably not a significant problem. In general, emission factors are determined by subtracting the emissions of a control plot (zero fertiliser) from the emissions of a fertilised plot. Since N deposition affects both plots, one would expect that N deposition is not included in the derived emission factor. Hence, the current default emission factor is most likely correct.

Note that the emission factors derived for both synthetic fertiliser and animal manure application should include corrections for volatilisation. In other words, the emission factor for these two sub-sources should represent the following: kg N_2O-N emitted / (kg N input- kg N volatilised)[15].

[15] In words: kg N_2O (as N) emitted divided by (kg N input minus kg N volatilised).

F_{BN} and F_{CR}: The factors required for calculation of F_{BN} and F_{CR} using the Tier 1a method are $Crop_{BF}$, $Crop_O$, $Frac_{NCRBF}$, $Frac_{NCRO}$, $Frac_R$, and $Frac_{BURN}$:

- $Crop_{BF}$ and $Crop_O$, $Frac_{NCRBF}$, $Frac_{NCRO}$, $Frac_R$, and $Frac_{BURN}$: Data on the production of N-fixing crops ($Crop_{BF}$), as well as non-N-fixing crops ($Crop_O$), can generally be obtained from national statistics. If such data are not available, FAO publishes data on crop production (see the website: www.apps.fao.org). As previously mentioned, the definition of the term $Crop_{BF}$ should be modified from the definition provided in the *IPCC Guidelines.* It should be defined so that it represents the products of all N-fixing crops, not just the seed yield of pulses and soybeans. For the fraction of nitrogen in N-fixing crops ($Frac_{NCRBF}$), non-N-fixing crops ($Frac_{NCRO}$), and the fraction of residues burned in the field ($Frac_{BURN}$) some crop-specific default values are provided in the *Good Practice Report* Table 4.16, and non-crop specific values are provided in Table 4-19, Reference Manual of the *IPCC Guidelines*. The *IPCC Guidelines* definition of the term $Frac_R$ should be modified to the fraction of total aboveground biomass that is removed from the field as crop product. Also, as already discussed, the default value for $Frac_R$ provided in Table 4-19 in the Reference Manual of the *IPCC Guidelines* is inconsistent with the default value '2' in Equation 4.28. If Equation 4.28 is used, a value of 0.50 should be used for $Frac_R$. For the fractions of residues burned, the same values that are used in the agricultural residue burning calculations should be used here.

- Some additional inputs are required for calculation of F_{BN} and F_{CR} using the Tier 1b method. These are $Res_{BF}/Crop_{BF}$, $Res_O/Crop_O$, $Frac_{DM}$, $Frac_{FUEL}$, $Frac_{CNST}$, $Frac_{FOD}$. The data needed to determine the residue to crop product mass ratio for N-fixing ($Res_{BF}/Crop_{BF}$) and non-N-fixing ($Res_O/Crop_O$) crops can generally be obtained from national statistics. If possible, crop-specific values should be used because of the variability among crops. If such data are not available nationally, default $Res_{BF}/Crop_{BF}$ and $Res_O/Crop_O$ values from *Good Practice Report* Table 4.16 can be used. If available, the dry matter content of the aboveground biomass for both N-fixing and non-N-fixing crops ($Frac_{DM}$) should also be obtained from national statistics and should be specific to specific crop types. Alternatively, default values for dry matter residue in Table 4.16 can be used. For the fractions of residue used as fuel ($Frac_{FUEL}$), used in construction ($Frac_{CNST}$), and used as fodder ($Frac_{FOD}$), country-specific values should be used. The values used for $Frac_{FUEL}$ must be consistent with those used in the energy calculations.

  It should also be noted that in the *IPCC Guidelines'* method for incorporation of crop residues, the contribution from root biomass from the harvested crop is not accounted for. Ideally, both the aboveground and the root biomass should be accounted for to include nitrogen from the total plant, but the root biomass cannot readily be estimated. For N-fixing crops, the *IPCC Guidelines* method does not include root biomass because it is assumed that the N contained in the aboveground part of the plant (crop product + shoots) is a proxy for the N_2O emissions associated with the processes of nitrogen fixation in the roots and movement aboveground.

F_{OS}: The area (in hectares) of organic soils cultivated annually (F_{OS}) should be collected from official national statistics. If this source is not available, data from FAO can be used.

4.7.1.4 COMPLETENESS

Complete coverage for this source category requires estimation of emissions for all of the anthropogenic inputs and activities (F_{SN}, F_{AM}, F_{BN}, F_{CR}, and F_{OS}, $F_{SEWSLUDGE}$), if they occur. Experience has shown that none of these sub-categories are likely to be missed in inventories, although countries may have difficulty obtaining accurate statistics for all sub-categories, particularly the amounts of crop residues (by crop type) that are typically incorporated into soils, and the area of cultivated organic soils.

Currently, the IPCC method does not explicitly address several activities that may enhance N_2O emissions, including:

- Consumption of commercial and non-commercial organic fertilisers other than animal manure and crop residues and sewage sludge;
- Production of N-fixing forage crops such as alfalfa;
- Production of mixed grass and N-fixing forage;
- Use of cover crops (catch crops) sown as green manure to reduce leaching of N in post-harvest periods;
- Ploughing of pasture lands;
- Use of plastic sheeting on horticultural soils;

- N deposition onto agricultural land from industrial sources (see Box 1: *Good Practice* in Derivation of Country-specific Emission Factors).

These additional activities can be considered, if appropriate, and if national activity data for these activities are collected. Some of these activities can be readily included in national inventories based on available information. For the additional commercial and non-commercial organic fertilisers, the default emission factor used for applied N and default fraction of animal manure N volatilised may be used. For N-fixing forage crops, use of the *good practice* method for biological nitrogen fixation is suggested, using harvested crop dry matter as the measure of total aboveground biomass. For cover (catch) crops, the *good practice* method for crop residues is suggested. Further research will be required to develop the flux data that is needed to develop emission factors for mixed grass and legume pastures, ploughing of grasslands, and use of plastic sheeting on horticultural areas.

4.7.1.5 DEVELOPING A CONSISTENT TIME SERIES

Ideally, the same method should be used throughout the entire time series. However, it is likely that the detail and disaggregation of emissions estimates from this source category will improve over time. In cases where some historical data are missing, it may be necessary to derive the data using other references or data sets. For example, annual data of areas for cultivated organic soils may need to be derived by interpolation from a longer time series based upon long-term trends (e.g. from decadal statistics over a 20- or 30-year period). Estimates of the amounts of crop residue incorporated annually may also need to be derived based on expert judgement. For general good practice guidance on ensuring time series consistency (see Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2).

It is important that the methods used reflect the results of action taken to reduce emissions and the methods and results are thoroughly documented. If policy measures are implemented such that activity data are affected directly (e.g. increased efficiency of fertiliser use resulting in a decrease in fertiliser consumption), the effect of the policy measures on emissions will be transparent, assuming the activity data are carefully documented. In cases where policy measures have an indirect effect on activity data or emission factors (e.g. a change in animal population feed practices to improve animal productivity that results in a change in animal excretion per head), inventory input data should reflect these effects. The inventory text should thoroughly explain the effect of the policies on the input data.

4.7.1.6 UNCERTAINTY ASSESSMENT

Uncertainties in estimates of direct emissions of N_2O from agricultural soils are caused by uncertainties related to the emission factors and activity data, lack of coverage of measurements, spatial aggregation, and lack of information on specific on-farm practices. Additional uncertainty will be introduced in an inventory when emission measurements that are not representative of all conditions in a country are used. For *good practice* measurements of direct N_2O emissions from soils for a specific sub-category (Smith *et al.*, 1999), the associated uncertainty is expected to be about 25%. In general, the reliability of activity data will be higher than that of the emission factors. As an example, further uncertainties may be caused by missing information on observance of laws and regulations related to handling and application of fertiliser and manure, and changing management practices in farming. Generally it is difficult to obtain information on the actual observance of laws and possible emission reductions achieved as well as information on farming practices.

Recent data (Smith *et al*, 1999; Mosier and Kroeze, 1999) indicate that measured emission factors for N_2O from applied nitrogen have a skewed distribution which is nearer to log-normal than normal, with a range from the order of 0.1% to the order of 10%. The best estimate of the 95% confidence limit ranges from one-fifth to 5 times the default emission factor of 1.25%, i.e. from about 0.25% to 6%.

For histosols, the uncertainty range is 1 to 80 kg N_2O-N $ha^{-1}yr^{-1}$ for soils in mid-latitudes and 5 to >100 kg N_2O-N $ha^{-1}yr^{-1}$ in tropical histosols.

As uncertainties for this source category are caused by many different factors, the uncertainty needs to be estimated using expert judgement based on knowledge of various error components. Chapter 6, Quantifying Uncertainties in Practice, provides advice on quantifying uncertainties in practice, including application of Monte Carlo methods.

4.7.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. N_2O emissions from agricultural soils (direct-soils, direct-grazing animals, and indirect) are reported in aggregate under the IPCC category 'Agriculture'. These three source categories should be listed separately in inventory reports. In addition, to improve the transparency of reporting, estimates of emissions from this source category should be reported by the following components:

- Synthetic fertiliser consumption;
- Animal manure applied to soils (other than that used as commercial fertiliser);
- Production of leguminous (N-fixing) crops;
- Crop residue incorporation;
- Organic soil cultivation.

If other components are included, such as commercial organic fertiliser, these should be reported separately as well. In addition to completing the reporting formats, the following additional information is necessary to document the estimate:

- **Activity data**: Sources of all activity data used in the calculations (i.e. complete citations for the statistical databases from which data were collected), and in cases when activity data were not available directly from databases, the information and assumptions that were used to derive the activity data. This documentation should include the frequency of data collection and estimation, and estimates of accuracy and precision.
- **Emission factors**: The sources of the emission factors that were used (specific IPCC default values or otherwise). In inventories in which country- or region-specific emission factors were used, or in which new methods (other than the default IPCC methods) were used, the scientific basis of these emission factors and methods should be completely described and documented. This includes defining the input parameters and describing the process by which these emission factors and methods are derived, as well as describing sources and magnitudes of uncertainties.
- **Emission results**: Significant fluctuations in emissions between years should be explained. A distinction should be made between changes in activity levels and changes in emission factors from year to year, and the reasons for these changes documented. If different emission factors are used for different years, the reasons for this should be explained and documented.

4.7.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to implement quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source category.

It is *good practice* to supplement the general QA/QC related to data processing, handling, and reporting, as outlined in Chapter 8, QA/QC, with source-specific category procedures discussed below. The persons who collect data are responsible for reviewing the data collection methods, checking the data to ensure that they are collected and aggregated or disaggregated correctly, and cross-checking the data with previous years to ensure that 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. Documentation is a crucial component of the review process because it enables reviewers to identify mistakes and suggest improvements.

Review of emission factors

- The inventory agency should review the default emission factors and document the rationale for setting specific values.
- If using country-specific factors, the inventory agency should compare them to the IPCC default emission factors, and, if accessible, the country-specific emission factors used by other countries with comparable

circumstances. Differences between country-specific factors and default or other country factors should be explained and documented.

Review of any direct measurements

- If using factors based on direct measurements, the inventory agency should review the measurements to ensure that they are representative of the actual range of environmental and soil management conditions, and inter-annual climatic variability, and were developed according to recognised standards (IAEA, 1992).
- The QA/QC protocol in effect at the sites should also be reviewed and the resulting estimates compared between sites and with default-based estimates.

Activity data check

- The inventory agency should compare country-specific data on synthetic fertiliser consumption with fertiliser usage data from the IFA and synthetic fertiliser consumption estimates from the FAO.
- The inventory agency should ensure that N excretion data are consistent with those used for the manure management systems source category.
- National crop production statistics should be compared to FAO crop production statistics.
- The inventory agency should ensure that the QA/QC described in Section 4.1 for livestock population characterisation has been implemented and that a consistent livestock population characterisation is used across sources.
- Country-specific values for various parameters should be compared to IPCC defaults.

External review

- The inventory agency should conduct expert (peer) review when first adopting or revising the method. Given the complexity and uniqueness of the parameters used in calculating country-specific factors for these categories, involve specialists in the field should be involved in such reviews.

4.8 INDIRECT N_2O EMISSIONS FROM NITROGEN USED IN AGRICULTURE

Nitrous oxide (N_2O) is produced naturally in soils and aquatic systems through the microbial processes of nitrification and denitrification. A number of agricultural and other anthropogenic activities add nitrogen (N) to soils and aquatic systems, increasing the amount of N available for nitrification and denitrification, and ultimately the amount of N_2O emitted. The emissions of N_2O that result from anthropogenic N inputs occur through a direct pathway (i.e. directly from the soils to which N is applied), and through a number of indirect pathways, including the leaching and runoff of applied N in aquatic systems, and the volatilisation of applied N as ammonia (NH_3) and oxides of nitrogen (NO_x) followed by deposition as ammonium (NH_4) and NO_x on soils and water.

4.8.1 Methodological issues

The *IPCC Guidelines* provide methods to estimate N_2O emissions from both direct and indirect pathways. This section provides *good practice guidance* on how to estimate indirect emissions of N_2O, while the direct pathway is covered in Section 4.7. Indirect emissions from both aquatic systems and agricultural soils are covered in Section 4.5.4 of the Reference Manual of the *IPCC Guidelines*. The method for estimating indirect N_2O emissions from human sewage, that is discharged into rivers or estuaries, is also presented in this section, although these emissions are reported under the Waste Sector.

4.8.1.1 CHOICE OF METHOD

The method in the *IPCC Guidelines* for estimating indirect N_2O emissions from N used in agriculture describes five separate pathways by which anthropogenic inputs of N become available for formation of N_2O:

- Atmospheric deposition on soils of NO_x and ammonium (NH_4)[16] with the sources of N including volatilisation of N inputs to soils, as well as combustion and industrial process sources;
- Leaching and runoff of N that is applied to, or deposited on, soils;
- Disposal of sewage N;
- Formation of N_2O in the atmosphere from NH_3 emissions originating from anthropogenic activities;
- Disposal of processing effluents from food processing and other operations.

Of these five sources, the *IPCC Guidelines* describe how to estimate emissions from: (i) that portion of the atmospheric deposition of NO_x and ammonium (NH_4) associated with the N from synthetic fertilisers and animal manure that have been applied to soils; (ii) that portion of the N from applied synthetic fertilisers and animal manure lost as leaching and runoff; and (iii) the discharge of sewage N into rivers or estuaries. However, there is no current method for estimating conversion of NH_3 to N_2O in the atmosphere. The basic equation shown in the *IPCC Guidelines* for estimating a country's indirect N_2O emissions ($N_2O_{indirect}$) (kg N/year) is:

EQUATION 4.30

INDIRECT N_2O EMISSIONS

$$N_2O_{indirect}\text{-}N = N_2O_{(G)} + N_2O_{(L)} + N_2O_{(S)}$$

Where:

$N_2O_{indirect}$-N = Emissions of N_2O in units of nitrogen

[16] The *IPCC Guidelines* refer to 'atmospheric deposition of NO_x and NH_3', but the process actually entails the volatilisation of applied N (or direct gaseous emissions of N) as oxides of nitrogen (NO_x) and ammonia (NH_3), transformations of these gases within the atmosphere (or upon deposition) and subsequent deposition as NO_x, nitric acid (HNO_3), and particulate ammonium (NH_4). NO_x is often hydrolysed in the atmosphere or upon deposition to form HNO_3, while NH_3 gas generally combines with atmospheric nitric acid or sulphuric acid (H_2SO_4) to form ammonium nitrate and ammonium sulphate aerosols, and hence is transformed to particulate ammonium form (NH_4).

$N_2O_{(G)}$ = N_2O produced from volatilisation of applied synthetic fertiliser and animal manure N, and its subsequent atmospheric deposition as NO_x and NH_4 (kg N/yr)

$N_2O_{(L)}$ = N_2O produced from leaching and runoff of applied fertiliser and animal manure N (kg N/yr)

$N_2O_{(S)}$ = N_2O produced from discharge of human sewage N into rivers or estuaries (kg N/yr) [17]

Conversion of N_2O-N emissions to N_2O emissions for reporting purposes is performed by using the following equation:

$$N_2O = N_2O\text{-}N \bullet 44/28$$

To apply the estimation method, the amount of N_2O produced from each of these indirect pathways must be determined. *Good practice guidance* on how to apply the *IPCC Guidelines* is provided below in order to clarify the method, and ensure consistency and completeness between source categories. The choice of *good practice* method is illustrated by the decision tree in Figure 4.8, Decision Tree for Indirect N_2O Emissions from Nitrogen used in Agriculture.

The terms Tier 1a and Tier 1b are used throughout *Good Practice Report,* Subsections 4.7 and 4.8, to differentiate between the equations in the *IPCC Guidelines* (Tier 1a) and new equations (Tier 1b) presented here. The Tier 1b equations represent increased precision due to expansion of the terms in the equations. However, while Tier 1b equations may be preferred, the activity data needed to use them may not be available. In these cases, use of the Tier 1a equations is appropriate. Estimating emissions using a combination of Tier 1a and Tier 1b equations for different sub-source categories, depending upon availability of activity data, is also acceptable. In some cases, there is no Tier 1b alternative because no refinement of the equation in the *IPCC Guidelines* was considered necessary.

Atmospheric deposition of NO_x and NH_4 ($N_2O_{(G)}$): Atmospheric deposition of nitrogen compounds such as nitrogen oxides (NO_x) and ammonium (NH_4) fertilises soils and surface waters, which results in enhanced biogenic N_2O formation. According to the *IPCC Guidelines*, the amount of applied agricultural N that volatilises and subsequently deposits on nearby soils is equal to the total amount of synthetic fertiliser nitrogen applied to soils (N_{FERT}) plus the total amount of animal manure nitrogen excreted in the country ($\sum_T(N_{(T)} \bullet Nex_{(T)})$) multiplied by appropriate volatilisation factors.[18] The volatilised N is then multiplied by an emission factor for atmospheric deposition (EF_4) to estimate $N_2O_{(G)}$ emissions.

The equation in the *IPCC Guidelines* is thus:

EQUATION 4.31

N_2O FROM ATMOSPHERIC DEPOSITION OF N (TIER 1a)

$$N_2O_{(G)}\text{-}N = [(N_{FERT} \bullet Frac_{GASF}) + (\textstyle\sum_T(N_{(T)} \bullet Nex_{(T)}) \bullet Frac_{GASM})] \bullet EF_4$$

Where[19]:

$N_2O_{(G)}$ = N_2O produced from atmospheric deposition of N, kg N/yr

N_{FERT} = total amount of synthetic nitrogen fertiliser applied to soils, kg N/yr [20]

$\sum_T(N_{(T)} \bullet Nex_{(T)})$ = total amount of animal manure nitrogen excreted in a country, kg N/yr

$Frac_{GASF}$ = fraction of synthetic N fertiliser that volatilises as NH_3 and NO_x, kg NH_3-N and NO_x-N/kg of N input

$Frac_{GASM}$ = fraction of animal manure N that volatilises as NH_3 and NO_x, kg NH_3-N and NO_x-N/kg of N excreted

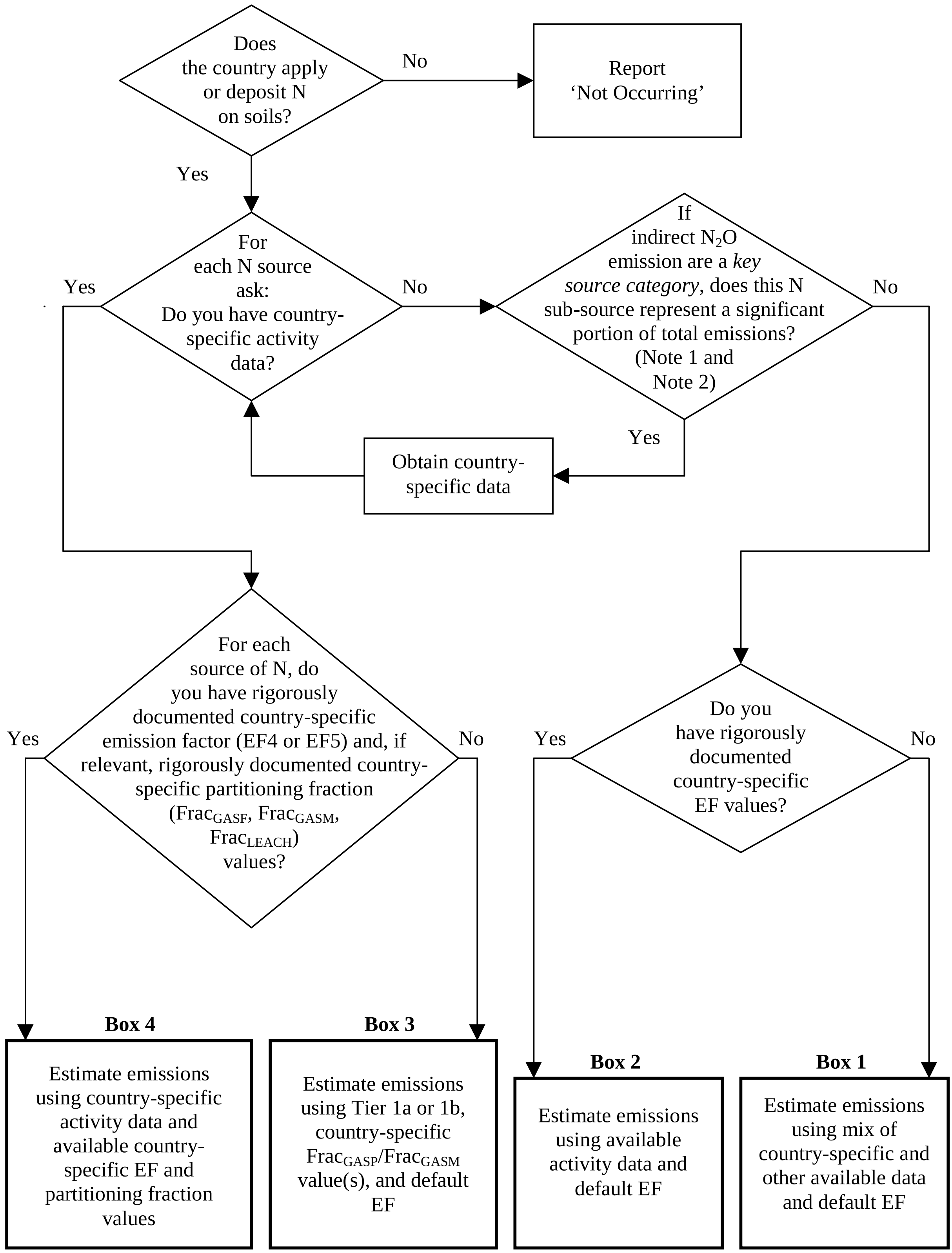
[17] Nitrous Oxide produced from human sewage ($N_2O_{(S)}$) is reported under the Waste sector.

[18] In this part of the *IPCC Guidelines*, the variable Nex is used for the total amount of animal manure produced. To be consistent with *Good Practice* in Section 4.4, this variable name has been revised to $\Sigma_T(N_{(T)} \bullet Nex_{(T)})$.

[19] Refer to Section 4.7 for more information on all of these terms except EF_4.

[20] The definition of N_{FERT} as total synthetic N fertiliser applied would cover application to forest soils.

Figure 4.8 Decision Tree for Indirect N_2O Emissions from Nitrogen Used in Agriculture



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

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

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, kg N_2O-N/kg NH_3-N and NO_x-N emitted

Use of Equation 4.31 is consistent with *good practice*. If more detailed data are available, however, a more complete estimate can be prepared.

First, the activity data used to estimate $N_2O_{(G)}$ can be expanded to include other forms of N applied to *all* soils, rather than just synthetic fertilisers and animal manure applied to agricultural soils. For example, sewage sludge, an additional form of organic N, is often applied to soils as a soil amendment or to dispose of the sludge. Sewage sludge nitrogen ($N_{SEWSLUDGE}$) can be included in this calculation if sufficient information is available.[21] The sludge input should be measured in units of N and multiplied by the volatilization factor that is used for animal manure N, $Frac_{GASM}$. The resulting equation for estimating the amount of N_2O produced from atmospheric deposition, renamed $N_2O_{(G\text{-}SOIL)}$, is:

EQUATION 4.32

N_2O FROM ATMOSPHERIC DEPOSITION OF N (TIER 1b)

$$N_2O_{(G\text{-}SOIL)}\text{-}N = \{(N_{FERT} \bullet Frac_{GASF}) + [\Sigma_T(N_{(T)} \bullet Nex_{(T)}) + N_{SEWSLUDGE}] \bullet Frac_{GASM}\} \bullet EF_4$$

This equation will ensure a more complete accounting of the N_2O emissions from the volatilisation and re-deposition of N applied to soils. These emissions should be reported within the Agriculture Sector.

Second, other sources of N deposited on soils $N_2O_{(G\text{-}i)}$ can be accounted for. The estimation of $N_2O_{(G\text{-}i)}$, can be undertaken to the extent that data allow the inclusion of deposited N from other anthropogenic activities associated with agriculture that release NO_x and NH_3. This would include emissions of NO_x and NH_3 (in units of N) from prescribed burning of savannas and field burning of agricultural residues.[22]

Equation 4.33 shows the *good practice* approach for estimating N_2O emissions from these additional indirect sub-categories associated with agriculture. For each sub-category '*i*,' (i.e. prescribed burning of savannas and field burning of agricultural residues) the amount of N emitted as NO_x and NH_3 is multiplied by EF_4.

EQUATION 4.33

N_2O FROM ADDITIONAL INDIRECT SUB-SOURCES

$$N_2O_{(G\text{-}i)}\text{-}N = (NO_{x\text{-}i} + NH_{3\text{-}i}) \bullet EF_4$$

Although the method for estimating these additional sub-categories of indirect emissions of N_2O is presented here, the estimates should be reported under the sector in which the originating activity is reported.

Leaching/runoff of applied or deposited nitrogen ($N_2O_{(L)}$): A large proportion of nitrogen is lost from agricultural soils through leaching and runoff. This nitrogen enters the groundwater, riparian areas and wetlands, rivers, and eventually the ocean, where it enhances biogenic production of N_2O. To estimate the amount of applied N that leaches or runs off (N_{LEACH}) using the method in the *IPCC Guidelines*, the total amount of synthetic fertiliser nitrogen (N_{FERT}) applied to the soils and the total amount of animal N excretion in the country ($\Sigma_T(N_{(T)} \bullet Nex_{(T)})$) are summed and then multiplied by the fraction of N input that is lost through leaching and runoff ($Frac_{LEACH}$). N_{LEACH} is then multiplied by the emission factor for leaching/runoff (EF_5) to obtain emissions of N_2O in units of N, $N_2O_{(L)}$. The equation in the *IPCC Guidelines* is thus:

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[21] Since there are no default data for the new parameter $N_{SEWSLUDGE}$, or guidance on collecting such data, this refinement should only be used if reliable country-specific data are available. Note that the sewage sludge activity data used to estimate indirect N_2O emissions should be the same as those used to estimate direct N_2O emissions (see Section 4.7).

[22] A complication in the estimation of N_2O emissions resulting from atmospheric deposition is that a significant fraction of NO_x and NH_3 may be deposited on the ocean, where EF_4 is probably not applicable and for which little information exists to define a more appropriate emission factor. This is particularly problematic for NO_x, which has a longer atmospheric lifetime than NH_3 and therefore is more likely to be transported far from its source (Smil, 1999). For the present, it is assumed that all NO_x and NH_3 are deposited on land.

EQUATION 4.34

DEPOSITED N FROM LEACHING/RUNOFF [23]

$$N_2O_{(L)}\text{-}N = [N_{FERT} + \sum_T (N_{(T)} \bullet Nex_{(T)})] \bullet Frac_{LEACH} \bullet EF_5$$

For *good practice*, this basic approach should be corrected so that it accounts for only the portion of animal manure N which is applied to soils (see Section 4.7).[24] As currently defined, the equation will overestimate N_2O emissions from this source because it does not reduce the total amount of animal manure N generated in a country ($\sum_T(N_{(T)} \bullet Nex_{(T)})$) by the amounts not applied to soil (i.e. the fractions used as fuel ($Frac_{FUEL\text{-}AM}$), feed ($Frac_{FEED\text{-}AM}$), and construction material ($Frac_{CNST\text{-}AM}$)). [25] The corrected equation is shown in Equation 4.35:

EQUATION 4.35

DEPOSITED N FROM LEACHING/RUNOFF (EXPANDED AS TO ANIMAL MANURE)

$$N_2O_{(L)}\text{-}N = N_{FERT} + \{\sum_T (N_{(T)} \bullet Nex_{(T)}) \bullet [1 - (Frac_{FUEL\text{-}AM} + Frac_{FEED\text{-}AM} + Frac_{CNST\text{-}AM})]\} \bullet Frac_{LEACH} \bullet EF_5$$

As with the estimation of $N_2O_{G\text{-}SOIL}$, if data are available the indirect emissions associated with the application of sewage sludge to soils should be included in the estimate (Tier 1b). In this case, the term $N_2O_{(L)}$ is renamed $N_2O_{L\text{-}SOIL}$ and the equation for estimating indirect N_2O emissions from leaching and runoff of N applied to soils is:

EQUATION 4.36

DEPOSITED N FROM LEACHING/RUNOFF (EXPANDED AS TO SEWAGE SLUDGE)

$$N_2O_{(L\text{-}SOIL)}\text{-}N = \left(N_{FERT} + \{\sum_T (N_{(T)} \bullet Nex_{(T)}) \bullet [1 - (Frac_{FUEL\text{-}AM} + Frac_{FEED\text{-}AM} + Frac_{CNST\text{-}AM})]\} + N_{SEWSLUDGE}\right) \bullet Frac_{LEACH} \bullet EF_5$$

Note that when estimating the animal manure N applied to soils, the calculation may need to be undertaken for each major animal species/category '*i*' because the fractions of animal manure used for fuel, feed, and construction may not be constant across all animal species/categories. In this case, Equation 4.36 should be rewritten as:

EQUATION 4.37

DEPOSITED N FROM LEACHING/RUNOFF (EXPANDED FOR MAJOR ANIMAL SPECIES/CATEGORIES)

$$N_2O_{(L\text{-}SOIL)}\text{-}N = \{N_{FERT} + \sum_i (N_{(EX)_i} \bullet [1 - (Frac_{(FUEL\text{-}AM)_i} + Frac_{(FEED\text{-}AM)_i} + Frac_{(CNST\text{-}AM)_i})] + N_{SEWSLUDGE}\} \bullet Frac_{LEACH} \bullet EF_5$$

The estimates derived from Equations 4.35, 4.36, and 4.37 should be reported as part of Agricultural Soil emissions within the Agriculture sector.

The term $N_2O_{(L)}$ can also be expanded to include other sources of N deposited on soils $N_2O_{(L\text{-}i)}$. If data allow, this should be undertaken to the extent that data allow the inclusion of deposition from other anthropogenic activities

[23] Equation 4.34 combines the equations for N_{LEACH} and $N_2O_{(L)}$ from the *IPCC Guidelines*.

[24] This correction ensures that the estimates prepared for this source are consistent with those prepared for direct N_2O emissions from agricultural soils, as described in Section 4.7.

[25] Note that in Equation 4.35, the fraction of N volatilised from fertiliser and animal manure is not accounted for. This is not an oversight but rather reflects the method's assumption that such N is subject to leaching after it redeposits on soil.

associated with agriculture that release NO_x and NH_3. This would include emissions of NO_x and NH_3 (in units of N) from prescribed burning of savannas and field burning of agricultural residues.

Equation 4.38 shows the *good practice* approach for estimating N_2O emissions from these additional indirect sub-source categories. For each source '*i*' (i.e. prescribed burning of savannas and field burning of agricultural residues), the amount of N emitted as NO_x and NH_3 is multiplied by $Frac_{LEACH}$ and EF_5.

EQUATION 4.38

DEPOSITED N FROM LEACHING/RUNOFF (EXPANDED AS TO ADDITIONAL INDIRECT SUB-SOURCES)

$$N_2O_{(L\text{-}i)}\text{-}N = (NO_{x\text{-}i} + NH_{3\text{-}i}) \bullet Frac_{LEACH} \bullet EF_5$$

Although the method for estimating these additional sources of indirect emissions of N_2O is presented here, the estimates should be reported under the source category in which the originating activity is reported.

Human consumption followed by municipal sewage treatment ($N_2O_{(S)}$): Human consumption of food results in the production of sewage, that can be processed in septic systems or wastewater treatment facilities, and then may seep into groundwater systems, be disposed of directly on land, or be discharged into a water source (e.g. rivers and estuaries). N_2O can be produced during all of these processes through nitrification and denitrification of sewage nitrogen. The *IPCC Guidelines* assume that N_2O emissions associated with sewage treatment and land disposal are negligible, so that all sewage nitrogen enters rivers and estuaries, where it is available for nitrification and denitrification. The method also recognises that some sewage N may be applied to soil as sludge. To estimate total sewage nitrogen (N_{SEWAGE}) using the method in the *IPCC Guidelines*, [26] the annual per capita protein consumption (PROTEIN, in kg protein/person-year) is multiplied by the national population (Nr_{PEOPLE}) and the fraction of protein that is nitrogen ($Frac_{NPR}$). N_{SEWAGE} is then multiplied by the emission factor for indirect emissions from sewage treatment (EF_6) to obtain N_2O emissions (in units of N) from discharge of sewage ($N_2O_{(S)}$). The two equations presented in the *IPCC Guidelines* to calculate N_2O emissions from discharge of sewage are combined in the single *good practice* equation below:

EQUATION 4.39

N_2O EMISSIONS FROM DISCHARGE OF SEWAGE[27]

$$N_2O_{(S)}\text{-}N = PROTEIN \bullet Nr_{PEOPLE} \bullet Frac_{NPR} \bullet EF_6$$

It is *good practice* to use this basic approach, if a basic approach has also been used for estimating indirect emissions from the atmospheric deposition and leaching/runoff pathways (i.e. if Equations 4.31 and 4.35 have been used). If a more detailed estimate has been prepared for these other pathways, however, a more detailed approach should also be used for this sub-category. To avoid double-counting of sewage N in this case, N_{SEWAGE} should be decreased by the amount of sewage N that is applied to soils in the form of sewage sludge ($N_{SEWSLUDGE}$), and that has already been accounted for in estimating both $N_2O_{(G\text{-}SOIL)}$ and $N_2O_{(L\text{-}SOIL)}$. Therefore, the more detailed equation for estimating $N_2O_{(S)}$, is :

EQUATION 4.40

N_2O EMISSIONS FROM DISCHARGE OF SEWAGE (EXPANDED AS TO SEWAGE SLUDGE)

$$N_2O_{(S)}\text{-}N = [(PROTEIN \bullet N_{PEOPLE} \bullet Frac_{NPR}) - N_{SEWSLUDGE}] \bullet EF_6$$

These emissions should be reported under Domestic and Commercial Wastewater in Chapter 5, Waste (Section 5.2).

[26] General guidance for estimating N_2O emissions from human sewage is provided in Section 6.4, Nitrous Oxide from Human Sewage, IPCC Guidelines, Vol. 3. For a detailed description of the proposed method, the reader is referred to Section 4.5.4 of the IPCC Guidelines, Reference Manual.

[27] Equation 4.39 combines the equations for N_{SEWAGE} and $N_2O_{(S)}$ from the *IPCC Guidelines*.

4.8.1.2 CHOICE OF EMISSION FACTORS

The method for estimating indirect N_2O emissions includes three emission factors: one associated with deposited nitrogen (EF_4), the second associated with nitrogen lost through leaching and runoff (EF_5), and the third associated with nitrogen in discharged sewage (EF_6).

Very little information exists, even on a global scale, for specifying EF_4, EF_5, and EF_6. Therefore, although the *IPCC Guidelines* normally encourages inventory agencies to substitute country-specific data for default emission factors, for this source category the default values should be used unless rigorously documented and peer-reviewed country-specific values have been developed. The following discussion summarises the default values and describes some refinements of them. For *good practice*, the IPCC default emission factors are presented in Table 4.18, Default Emission Factors for Estimating Indirect N_2O Emissions from N used in Agriculture.

- **Emission factor for deposited nitrogen (EF_4):** The default value for EF_4 is 0.01 kg N_2O-N/kg NH_4-N and NO_x-N deposited. Country-specific values for EF_4 should be used with great caution because of the special complexity of transboundary atmospheric transport. Although inventory agencies may have specific measurements of N deposition and associated N_2O flux, in many cases the deposited N may not have originated in their country. Similarly, some of the N that volatilises in their country may be transported to and deposited in another country, where different conditions that affect the fraction emitted as N_2O may prevail.

- **Emission factor for leaching and runoff (EF_5):** This value should be updated based on a recent re-examination of one of the factors from which it was derived. However, more research will be required before a new default value can be established.

- **Emission factor for discharged sewage effluent:** The default value for EF_6 is 0.01 kg N_2O-N/kg N. This value was derived by adding estimates of emission factors for rivers (EF_{5-r} = 0.0075) and estuaries (EF_{5-e} = 0.0025). Country-specific values of EF_6 must be used with great caution because of the complexity of this emission pathway.

TABLE 4.18
DEFAULT EMISSION FACTORS FOR ESTIMATING INDIRECT N_2O EMISSIONS FROM N USED IN AGRICULTURE

Emission Factor	IPCC Default Value
EF_4 (kg N_2O-N/kg NH_4-N & NO_x-N deposited)	0.01
EF_5 (kg N_2O-N/kg N leached & runoff)	0.025
EF_6 (kg N_2O-N/kg sewage N discharged sewage effluent)	0.01
Source: *IPCC Guidelines*, Reference Manual, Table 4-23.	

4.8.1.3 CHOICE OF ACTIVITY DATA

Much of the activity data required to estimate indirect N_2O emissions, such as fertiliser consumption and livestock nitrogen excretion, will have been previously developed for estimating emissions from other source categories. Table 4.19, Data for Estimating Indirect N_2O, summarises the key activity data required, and describes where to obtain them. It is essential that the same data sets be used across source categories to ensure consistency in emission estimates.

As Table 4.19 shows, most of the activity data will be data developed for other source category estimates. *Good practice* in obtaining that data is described in the appropriate sections. The discussion below summarises *good practice* for developing the activity data:

- **Estimating NO_x and NH_3 emissions from new source categories included for good practice:** Emissions of NO_x and NH_3 resulting from savanna burning and agricultural residue burning are required to estimate indirect N_2O emissions from these activities. Estimation methods and default emission factors (or emission ratios) for estimating NO_x emissions are included for these sub-categories in the *IPCC Guidelines* under their respective sectors or sub-sectors. The same methods used to estimate NO_x emissions for each sub-category should be used to estimate NH_3 emissions, but the NO_x emission factors should be replaced with NH_3 emission factors. A default emission factor of 0.038 Gg NH_3-N/Gg fuel N (Crutzen and Andreae, 1990)[28] may be used to estimate NH_3 emissions from savanna burning and agricultural residue burning if country-specific emission factors are not available.

TABLE 4.19 DATA FOR ESTIMATING INDIRECT N_2O	
Activity Data	**How to Obtain**
N_{FERT}	From estimate of N_{FERT} value collected for Direct N_2O Emissions from Agricultural Soils
$\sum_T(N_{(T)} \bullet N_{ex(T)})$	From estimate of $\sum_T(N_{(T)} \bullet N_{ex(T)})$ value collected for Direct N_2O Emissions from Agricultural Soils
$N_{SEWSLUDGE}$	From estimate of $N_{SEWSLUDGE}$ value collected for Direct N_2O Emissions from Agricultural Soils
PROTEIN	Food and Agricultural Organisation (FAO)
Nr_{PEOPLE}	Food and Agricultural Organisation (FAO)
$Frac_{NPR}$	See Table 4-24 in the *IPCC Guidelines* Reference Manual
$Frac_{LEACH}$	See Table 4-24 in the *IPCC Guidelines* Reference Manual
$Frac_{GASF}$	See Table 4-19 in the *IPCC Guidelines* Reference Manual
$Frac_{GASM}$	See Table 4-19 in the *IPCC Guidelines* Reference Manual
$Frac_{FUEL\text{-}AM}$	From estimate of $Frac_{FUEL\text{-}AM}$ value collected for Direct N_2O Emissions from Agricultural Soils
$Frac_{FEED\text{-}AM}$	From estimate of $Frac_{FEED\text{-}AM}$ value collected for Direct N_2O Emissions from Agricultural Soils
$Frac_{CNST\text{-}AM}$	From estimate of $Frac_{CNST\text{-}AM}$ value collected for Direct N_2O Emissions from Agricultural Soils

- **Partitioning fractions for volatilisation ($Frac_{GASF}$, $Frac_{GASM}$):** For the fraction of nitrogen that volatilises as NH_3 and NO_x from applied synthetic fertilisers ($Frac_{GASF}$) and animal manure and sewage sludge ($Frac_{GASM}$), default values of 10% and 20%, respectively, are presented in the *IPCC Guidelines*. Country-specific volatilisation fractions can be used with reasonable documentation.
- **Partitioning fraction for leaching ($Frac_{LEACH}$):** A default value of 30% is presented in the *IPCC Guidelines* for $Frac_{LEACH}$. Note, however, that this default value was largely based on mass balance studies comparing agricultural N inputs to N recovered in rivers. Agricultural practices (e.g. irrigation, frequent ploughing, and drainage tiles) can promote heavy leaching losses of N applied to agricultural soils. However, for N that is deposited *away* from agricultural land, a lower value of $Frac_{LEACH}$ may be more appropriate. Future revisions of the method may reflect this consideration. Due to difficulties in developing a reliable factor for this source category, inventory agencies should use caution and provide rigorous documentation if using a country-specific factor.
- **Partitioning fraction for nitrogen in protein ($Frac_{NPR}$):** A default values of 16% is presented in the *IPCC Guidelines* for the fraction of animal and plant protein that is nitrogen ($Frac_{NPR}$). This term is not highly variable, and therefore country-specific values are unnecessary.

4.8.1.4 COMPLETENESS

Complete coverage for indirect N_2O emissions from nitrogen used in agriculture requires estimation of emissions from all of the agricultural input activities (i.e. N_{FERT}, $\sum_T(N_{(T)} \bullet Nex_{(T)})$, and $N_{SEWSLUDGE}$). If data are available, $N_{SEWSLUDGE}$ application (on all soils) can also be included. Complete coverage for indirect N_2O emissions from human sewage requires estimation of emissions from the discharge of sewage N (i.e. N_{SEWAGE}, N_{SEWAGE} minus $N_{SEWSLUDGE}$).

[28] Table 2 of Andreae and Crutzen (1990) is the basis for the NO_x and NH_3 emission factors associated with biomass burning. Note that this table also lists an emission factor of 0.034 mole RCN per mole total N in biomass, on par with the NH_3 emission factor. RCN is a form of nitrogen which is biologically available and therefore subject to microbial nitrification, denitrification, and N_2O production. Furthermore, Table 2 of Andreae and Crutzen (1990) only accounts for about 70% of biomass N, implying that combustion may yield additional, as yet unidentified forms of biologically available nitrogen. Thus by only accounting for NO_x and NH_3 emissions, the method likely underestimates the total amount of biologically available nitrogen released by biomass burning.

If data are available, the inventory should also include indirect N_2O emissions from savanna burning and agricultural residue burning. These emissions are based upon direct emissions of NO_x and NH_3 from these activities.

4.8.1.5 DEVELOPING A CONSISTENT TIME SERIES

Emission estimates over a time series should be made using the same method (in terms of level of detail). Inter-annual changes in $Frac_{GASF}$, $Frac_{GASM}$, $Frac_{LEACH}$, $Frac_{NPR}$, EF_4, EF_5, and EF_6 are not expected unless mitigation measures are undertaken. These factors should be changed only with the proper justification and documentation. If updated defaults for any of these variables become available through future research, inventory agencies may recalculate their historical emissions. For general *good practice* guidance on ensuring consistency in a time series, see Chapter 7, Methodological Choice and Recalculation, Section 7.3.2.2.

4.8.1.6 UNCERTAINTY ASSESSMENT

Information about emission factors (EF_4, EF_5, and EF_6), leaching and volatilisation fractions are sparse and highly variable. Expert judgement indicates that emission factor uncertainties are at least in order of magnitude and volatilisation fractions of about +/–50%. Uncertainties in activity data estimates should be taken from the corresponding direct emissions source categories. Chapter 6, Quantifying Uncertainties in Practice, provides advice on quantifying uncertainties in practice including combining expert judgements and empirical data into overall uncertainty estimates.

4.8.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. The worksheets in the *IPCC Guidelines* (Workbook) for calculating indirect N_2O from agricultural soils provide for transparent documentation of the default method of the *IPCC Guidelines*, and the data used to implement the method. However, to implement *good practice*, these worksheets should be expanded to incorporate the new variables that have been added to the deposition and leaching calculations (i.e. $N_{SEWSLUDGE}$, $Frac_{FUEL-AM}$, $Frac_{FEED-AM}$, and $Frac_{CNST-AM}$) and should be revised to reflect Equations 4.31 and 4.35 or 4.36.

The worksheets in the Workbook of the *IPCC Guidelines* used for calculating indirect N_2O from human sewage also provide for transparent documentation of the default method and the data used to implement the method. However, to implement the *good practice* approach, these worksheets must be expanded to incorporate the new variable that has been added to the calculation (i.e. $N_{SEWSLUDGE}$) and must be revised to reflect Equation 4.40.

To implement *good practice* for indirect N_2O emissions from savanna burning and agricultural residue burning, new worksheets must be developed for each of these sub-categories. The worksheet for indirect N_2O emissions from savanna burning and agricultural residue burning should reflect Equations 4.33 and 4.38.

The reporting tables in the Reporting Instructions are inadequate. Direct and indirect agricultural N_2O sources are reported together as one entry entitled 'agricultural soils' rather than separately. Furthermore, the title is a misnomer for indirect emissions, since a large fraction of these emissions occurs from aquatic systems. To improve the transparency of reporting, estimates of emissions from deposition and leaching should be reported separately. An explicit entry for indirect emissions from human sewage should be added in the Waste section. Entries for the new indirect N_2O sources (savanna burning and agricultural residue burning) should also be added to the reporting tables.

In addition to completing the reporting formats, the following additional information is necessary to document indirect N_2O emission estimates:

- **Activity data**: References for all activity data used in the calculations (i.e. complete citations for the statistical database from which data were collected), and in cases when activity data were not available directly from databases, the information and assumptions that were used to derive the activity data. This documentation should include the frequency of data collection and estimation, and estimates of accuracy and precision.
- **Emission factors**: References for the emission factors that were used (specific IPCC default values or otherwise). In inventories in which country- or region-specific emission factors were used, or in which new methods (other than the default IPCC methods) were used, the scientific basis of these emission factors or

methods should be completely described and documented. This includes defining the input parameters and describing the process by which these emission factors or methods are derived, as well as describing sources and magnitudes of uncertainties.

- **Emission results**: Significant fluctuations in emissions between years should be explained. A distinction should be made between changes in activity levels and changes in emission factors from year to year and the reasons for these changes documented. If different emission factors are used for different years, the reasons for this should be explained and documented.

4.8.3 Inventory quality assurance/quality control (QA/QC)

It is *good practice* to implement quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source.

It is *good practice* to supplement the general QA/QC related to data processing, handling and reporting, as outlined in Chapter 8, QA/QC, with source-specific procedures discussed below. The persons who collect data are responsible for reviewing the data collection methods, checking the data to ensure that they are collected and aggregated or disaggregated correctly, and cross-checking the data with previous years to ensure that 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. Documentation is a crucial component of the review process because it enables reviewers to identify mistakes and suggest improvements.

Review of emission factors

- The inventory agency should review the parameters, equations and calculations used to develop the emission factors. These QC steps are particularly important for subcategories in this source category because of the number of parameters that are used to construct the emission factors.

- If using country-specific factors, the inventory agency should compare them to the IPCC default factors. This is particularly important for the emission factors for deposited N and for discharged sewage, where caution should be used in developing country-specific factors.

Activity data check

- Since many of the activity parameters used for this source category are also used for other agricultural sources, it is critical to ensure that consistent values are being used.

- If using country-specific values for various parameters, (i.e. $Frac_{LEACH}$), the inventory agency should compare them to the IPCC defaults. Rigorous documentation of the development of country-specific values should also be maintained.

External review

- Agricultural specialists (particularly nitrogen cycle specialists) as well as agricultural industry and other stakeholders, should peer review the inventory estimates and all important parameters and emission factors.

4.9 CH_4 EMISSIONS FROM RICE PRODUCTION

4.9.1 Methodological issues

Anaerobic decomposition of organic material in flooded rice fields produces methane (CH_4), which escapes to the atmosphere primarily by transport through the rice plants. The annual amount emitted from an area of rice acreage is a function of rice cultivar, number and duration of crops grown, soil type and temperature, water management practices, and the use of fertilisers and other organic and inorganic amendments.

4.9.1.1 CHOICE OF METHOD

The *IPCC Guidelines* outline one method for estimating emissions from rice production, that uses annual harvested areas[29] and area-based seasonally integrated emission factors.[30] In its most simple form, the IPCC method can be implemented using national activity data (i.e. national total area harvested) and a single emission factor. However, the conditions under which rice is grown (e.g. water management practices, organic fertiliser use, soil type) may be highly variable within a country, and these conditions can affect seasonal CH_4 emissions significantly. The method can be modified to account for this variability in growing conditions by disaggregating national total harvested area into sub-units (e.g. harvested areas under different water management regimes), and multiplying the harvested area for each sub-unit by an emission factor that is representative of the conditions that define the sub-unit. With this disaggregated approach, total annual emissions are equal to the sum of emissions from each sub-unit of harvested area. Thus, the basic equation is as follows:

EQUATION 4.41

CH_4 EMISSIONS FROM RICE PRODUCTION

$$\text{Emissions from Rice Production (Tg/yr)} = \sum_i \sum_j \sum_k (EF_{ijk} \bullet A_{ijk} \bullet 10^{-12})$$

Where:

EF_{ijk} = a seasonally integrated emission factor for *i*, *j*, and *k* conditions, in g CH_4/m^2

A_{ijk} = annual harvested area for *i*, *j*, and *k* conditions, in m^2/yr

i, j, and k = represent different ecosystems, water management regimes, and other conditions under which CH_4 emissions from rice may vary (e.g. addition of organic amendments)

The different conditions that should be considered include rice ecosystem type, water management regime, type and amount of organic amendments, and soil type. The primary rice ecosystem types, and water management regimes in each ecosystem type, are listed in Table 4.20, IPCC Default CH_4 Emission Scaling Factors for Rice Ecosystems and Water Management Regimes Relative to Continuously Flooded Fields. If rice is produced in distinct regions within the country (e.g. district, province), the equation above should be applied to each region. National emissions are equal to the sum of the regional estimates. In addition, if more than one crop is harvested in a particular region during the year, and the conditions of cultivation (e.g. use of organic amendments) vary among cropping seasons, then for that region, emissions should be estimated for each cropping season, and then summed over all cropping seasons. In this case, the activity data are cultivated area, rather than harvested area.

If rice is a *key source category* (as defined in Chapter 7, Methodological Choice and Recalculation), inventory agencies are encouraged to:

- Implement the IPCC method at the most disaggregated level possible;

29 In case of multiple cropping during the same year, 'harvested area' is equal to the sum of the area cultivated for each cropping.

30 An emission factor represents the total missions over an entire cropping season (from land preparation until harvest or post season drainage) per unit area. As in Appendix 4A.3, emission factors should be based on measurements over the entire period of flooding, and should account for fluxes of soil-entrapped methane that typically occur upon drainage.

- Incorporate as many of the characteristics (i, j, k, etc.,) that influence CH_4 emissions as possible;
- Develop country-specific emission factors to reflect the local impacts of these characteristics, preferably through collection of field data;
- Use emission factors and activity data at the same level of aggregation.

The decision tree in Figure 4.9, Decision Tree for CH_4 Emissions from Rice Production, guides inventory agencies through the process of applying the *good practice* IPCC approach. Implicit in this decision tree is a hierarchy of disaggregation in implementing the IPCC method. Within this hierarchy, the level of disaggregation utilised by an inventory agency will depend upon the availability of activity and emission factor data, as well as the importance of rice as a contributor to national greenhouse gas emissions. The specific steps and variables in this decision tree, and the logic behind it, are discussed in the text that follows the decision tree.

4.9.1.2 CHOICE OF EMISSION FACTORS

Ideally, inventory agencies will have seasonally integrated emission factors for each commonly occurring set of rice production conditions in the country developed from standardised field measurements. These local, measurement-based emission factors account for the specific mix of different conditions that influence CH_4 emissions in one area implicitly. The most important conditions that influence rice emissions are summarised in Box 4.2:

BOX 4.2
CONSIDERATIONS FOR RICE PRODUCTION EMISSION FACTOR DEVELOPMENT

The following rice production characteristics should be considered in developing emission factors:

Regional differences in rice cropping practices: If the country is large and has distinct agricultural regions, a separate set of measurements should be performed for each region.

Multiple crops: If more than one crop is harvested on a given area of land during the year, and the growing conditions vary among cropping seasons, emissions should be measured for each season.

Ecosystem type: At a minimum, separate measurements should be undertaken for each ecosystem (i.e. irrigated, rainfed, and deep water rice production).

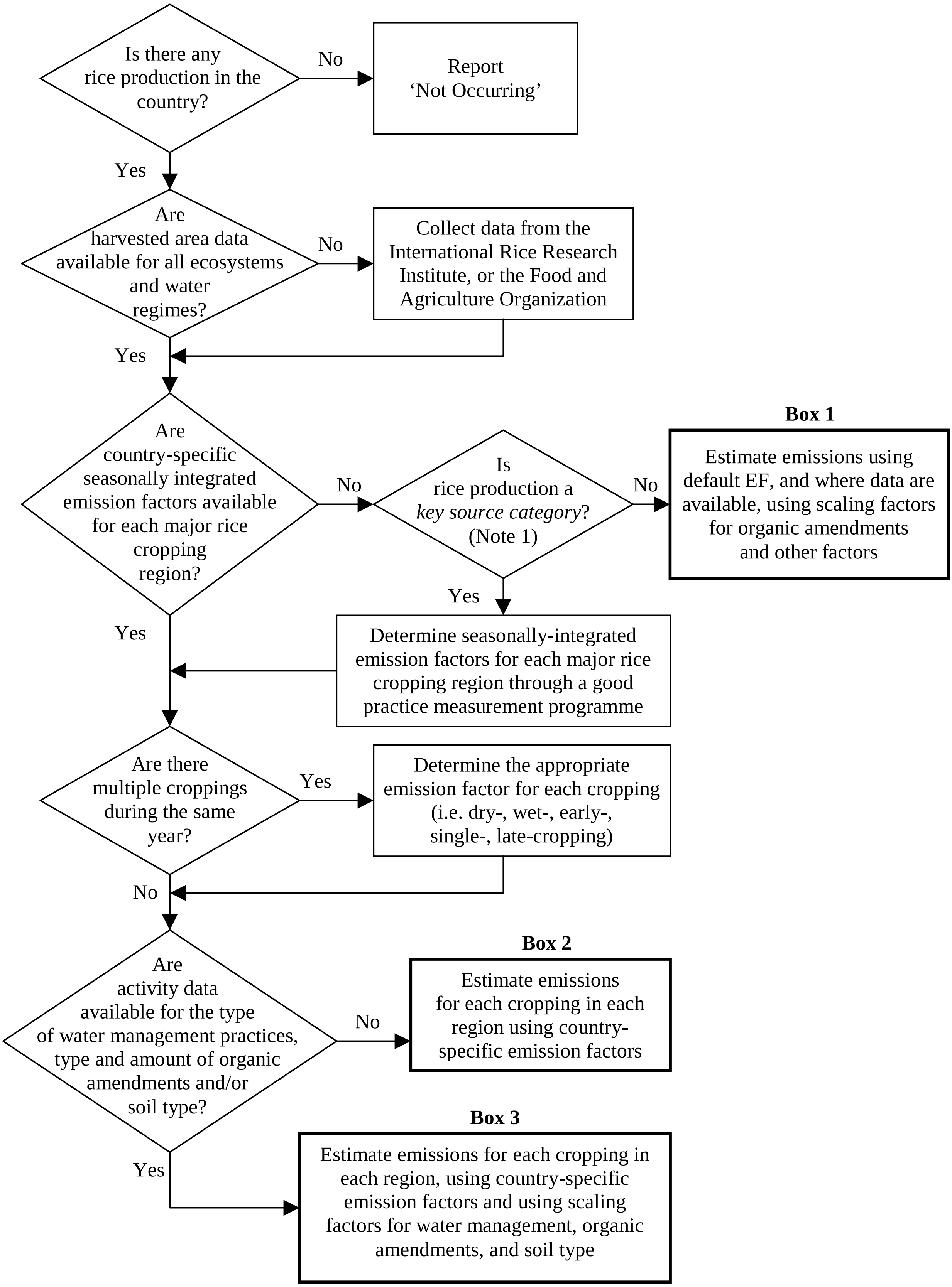
Water management regime: Each ecosystem should be broken down further to account for different water management practices (e.g. continuously flooded vs. intermittently flooded).

Addition of organic amendments: Measurements should be designed so that the effect of organic amendments (e.g. green manure, rice straw, animal manure, compost, weeds and other aquatic biomass, etc.) on CH_4 emissions can be quantified.

Soil type: Inventory agencies are encouraged to make every effort to undertake measurements on all major soil types under rice cultivation because of the significant influence that soil type can have on CH_4 emissions. Up to now the soil factor has not been taken into account in the *IPCC Guidelines* because data on harvested area by (major) soil type are not available from the standard activity data sources. However, with the recent developments of models to simulate CH_4 emissions from rice fields, deriving scaling factors for major soil types grown to rice will be feasible in the near future (e.g. Ding *et al.*, 1996, and Huang *et al.*, 1998). Combining measured or model-simulated soil type-specific scaling factors and a breakdown of rice acreage by soil type would further improve inventory accuracy if available.

Since some countries grow rice under a wide diversity of conditions, a complete set of local measurement-based emission factors may not be possible. In this case, inventory agencies are encouraged to first obtain a seasonally integrated emission factor for continuously flooded fields without organic amendments (EF_c), which is to be used as a starting point, and use scaling factors to adjust it to account for different conditions. The adjusted emission factors can then be determined using the following equation:

Figure 4.9 Decision Tree for CH_4 Emission from Rice Production



Note 1: A *key source category* is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of direct greenhouse gases in terms of the absolute level of emissions, the trend in emissions, or both. (See Chapter 7, Methodological Choice and Recalculation, Section 7.2, Determining National Key Source Categories.)

EQUATION 4.42
ADJUSTED SEASONALLY INTEGRATED EMISSION FACTOR

$$EF_i = EF_c \bullet SF_w \bullet SF_o \bullet SF_s$$

Where:

EF_i = Adjusted seasonally integrated emission factor for a particular harvested area

EF_c = Seasonally integrated emission factor for continuously flooded fields without organic amendments

SF_w = Scaling factor to account for the differences in ecosystem and water management regime (from Table 4.20)

SF_o = Scaling factors should vary for both types and amount of amendment applied. (from Table 4.21, Dose-Response Table for Non-Fermented Organic Amendments)

SF_s = Scaling factor for soil type, if available

The seasonally integrated emission factor for continuously flooded fields of major soil types without organic amendments should be determined through field measurements according to *good practice* procedures, as discussed in Appendix 4A.3. If data to determine EF_c are not yet available, the IPCC default of 20 g/m^2 may be used.

Scaling factors can be used to adjust the seasonally integrated emission factor for continuously flooded fields (EF_c) to account for the various conditions discussed in Box 4.2. In order, the three most important scaling factors are rice ecosystem/water management regime, organic amendments, and soil type. Country-specific scaling factors should only be used if they are based on well-researched and documented measurement data. If data to determine scaling factors are not yet available, IPCC defaults can be used.

Water management system: The main types of methane-emitting rice ecosystems are irrigated, rainfed and deep water. Within each ecosystem are water management systems, which affect the amount of CH_4 emitted during a cropping season. Table 4.20 provides IPCC default scaling factors for SF_w that can be used when country-specific data are unavailable. Scaling factors for additional ecosystem types and water management regimes can be applied only if country-specific data are available.

TABLE 4.20
IPCC DEFAULT CH_4 EMISSION SCALING FACTORS FOR RICE ECOSYSTEMS AND WATER MANAGEMENT REGIMES RELATIVE TO CONTINUOUSLY FLOODED FIELDS (WITHOUT ORGANIC AMENDMENTS)

Category	Water Management Regime		Scaling Factor (SF_w)
Upland	None		0
Lowland	Irrigated	Continuous Flooded	1.0
		Intermittently Flooded – Single Aeration	0.5 (0.2-0.7)
		Intermittently Flooded – Multiple Aeration	0.2 (0.1-0.3)
	Rainfed	Flood prone	0.8 (0.5-1.0)
		Drought prone	0.4 (0-0.5)
	Deep water	Water depth 50-100 cm	0.8 (0.6-1.0)
		Water depth > 100 cm	0.6 (0.5-0.8)

Source: *IPCC Guidelines*, Reference Manual, Table 4-12.

Organic amendments: *Good practice* is to develop a scaling factor (SF_o) that incorporates information on the type and amount of organic amendment applied (rice straw, animal manure, green manure, compost, and agricultural wastes). On an equal mass basis, more CH_4 is emitted from amendments containing higher amounts of easily decomposable carbon, and emissions also increase as more of each organic amendment is applied. Table 4.21 presents an approach to vary the scaling factor according to the amount of amendment applied.

Theoretically, the different amendments should be ranked according to the carbon content per unit of weight, but most often only information on the amount applied is available. In this case, the inventory agency should distinguish between fermented and non-fermented organic amendments. CH_4 emissions from fermented amendments (e.g. compost, residue of biogas pits) are significantly lower than non-fermented amendments because they contain much less easily decomposable carbon. Denier van der Gon and Neue (1995) empirically determined a reduction factor of six implying that the increase in CH_4 emission upon application of 12 t/ha compost is comparable to the increase upon application of 2 t/ha non-fermented organic amendment.

TABLE 4.21

DOSE-RESPONSE TABLE FOR NON-FERMENTED ORGANIC AMENDMENTS

Amount applied as dry matter (t/ha)	Scaling factor (SF_o)	Range
1-2	1.5	1-2
2-4	1.8	1.5-2.5
4-8	2.5	1.5-3.5
8-15	3.5	2-4.5
15+	4	3-5

Note: To use the table for fermented organic amendments, divide the amount applied by six.

Source: Derived from Denier van der Gon and Neue, 1995.

Soil types: In some cases emission data for different soil types are available and can be used to derive SF_s. The major motivation to incorporate soil type as a scaling factor is that both experiments and mechanistic knowledge confirm its importance. It is anticipated that in the near future simulation models will be capable of producing soil-specific scaling factors.

4.9.1.3 CHOICE OF ACTIVITY DATA

Activity data consist of rice production and harvested area statistics, which should be available from a national statistics agency. The activity data should be broken down by rice ecosystem or water management type. If these data are not available in-country, they can be downloaded from an FAO website: (http://www.fao.org/ag/agp/agpc/doc) or can be obtained from IRRI's World Rice Statistics (e.g. IRRI, 1995). Most likely, the accuracy of activity data will be high compared to the accuracy of the emission factor. However, for various reasons the area statistics may be biased and a check of the harvested area statistics for (parts of) the country with remotely sensed data is encouraged.

In addition to the essential activity data requested above, it is *good practice* to match data on organic amendments and soil types to the same level of disaggregation as the activity data. It may be necessary to complete a survey of cropping practices to obtain data on the type and amount of organic amendments applied.

4.9.1.4 COMPLETENESS

Complete coverage for this source category requires estimation of emissions from the following activities, where present:

- If soil submergence is not limited to the actual rice growing season, emissions outside of the rice growing season should be included (e.g. from a flooded fallow period);
- Other rice ecosystem categories, like swamp, inland-saline or tidal rice fields may be discriminated within each sub-category according to local emission measurements;
- If more than one rice crop is grown annually, these rice crops should be reported independently according to the local definition (e.g. early rice, late rice, wet season rice, dry season rice). The rice crops may fall into different categories with a different seasonally integrated emission factor and different correction factors for other modifiers like organic amendments.

4.9.1.5 DEVELOPING A CONSISTENT TIME SERIES

The emission estimation method should be applied consistently to every year in the time series, at the same level of disaggregation. If detailed activity level data are unavailable for earlier years, emissions for these years should be re-calculated according to the guidance provided in Chapter 7, Methodological Choice and Recalculation, Section 7.3. If there have been significant changes in agricultural practices affecting CH_4 emissions over the times series, the rice estimation method should be implemented at a level of disaggregation which is sufficient to discern the effects of these changes. For example, various trends in (Asian) rice agriculture such as the adoption of new rice varieties, increasing use of inorganic fertiliser, improved water management, changing use of organic amendments, and direct seeding may lead to increases or decreases in overall emissions. To weigh the impact of these changes, it may be necessary to use model studies.

4.9.1.6 UNCERTAINTY ASSESSMENT

Table 4.22 presents a default emission factor, default scaling factors, and ranges for the default values. The range of emission factor, defined as the standard deviation about the mean, indicates the uncertainty associated with this default value for this source category. The uncertainty may be influenced by the following:

Natural Variability: The natural variability is a result of variations in natural controlling variables, such as annual climate variability, and variability within units that are assumed to be homogenous, such as spatial variability in a field or soil unit. For this source category, *good practice* should permit determination of uncertainties using standard statistical methods when enough experimental data are available. Studies to quantify some of this uncertainty are rare but available (e.g. for soil type induced variability). The variability found in such studies is assumed to be generally valid. For more detail, see Sass (1999).

Lack of activity data and documentation: Important activity data necessary to apply scaling factors (i.e. data on cultural practices and organic amendments) may not be available in current databases/statistics. Estimates of the fraction of rice farmers using a particular practice or amendment must then be based on expert judgement, and the range in the estimated fraction should also be based on expert judgement. As a default value for the uncertainty in the fraction estimate, ± 0.2 is proposed (e.g. the fraction of farmers using organic amendment estimated at 0.4, the uncertainty range being 0.2-0.6). Chapter 6, Quantifying Uncertainties in Practice, provides advice on quantifying uncertainties in practice including combining expert judgements and empirical data into overall uncertainty estimates.

TABLE 4.22
DEFAULT EMISSION FACTOR, DEFAULT SCALING FACTORS, AND RANGES FOR CH_4 EMISSIONS FROM RICE FIELD

Emission component	Default value	Ranges
Standard emission factor (EF)	20 g CH_4 m^{-2} $season^{-1}$	12-28 g CH_4 m^{-2} $season^{-1}$
Scaling factor water management SF_w	See Table 4.20	Table 4.20
Scaling factor organic amendments SF_o	2	1.5-5
Scaling factor soil types SF_s	1	0.1-2
Source: *IPCC Guidelines* and Judgement by Expert Group (see Co-chairs, Editors and Experts; CH4 Emissions from Rice Production).		

4.9.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. It is *good practice* to document the emission estimate by reporting the information required to fill out the rice worksheet in the Workbook of the *IPCC Guidelines*. Inventory agencies that do not use the worksheets should provide comparable information. If the emission estimate is disaggregated by region, information on each region should be reported.

The following additional information should be reported, if available, to ensure transparency:

- Water management practices;
- The types and amounts of organic amendments used. (Incorporation of rice straw or residues of the previous (non-rice) crop should be considered an organic amendment, although it may be a normal production practice and not aimed at increasing nutrient levels as is the case with manure additions);
- Soil types used for rice agriculture;
- Number of rice crops grown annually;
- Most important rice cultivars grown.

When simple default emission factors are used to estimate CH_4 emissions, uncertainty can increase dramatically. Inventory agencies using country-specific emission factors should provide information on the origin and basis of the factor, compare it to other published emission factors, explain any significant differences, and attempt to place bounds on the uncertainty.

4.9.3 Inventory quality assessment/quality control (QA/QC)

It is *good practice* to implement quality control checks as outlined in Chapter 8, Quality Assurance and Quality Control, Table 8.1, Tier 1 General Inventory Level QC Procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, and quality assurance procedures may also be applicable, particularly if higher tier methods are used to determine emissions from this source.

A detailed treatment on inventory QA/QC for field measurement is given by Sass (1999) and in Appendix 4A.3. Some important issues are highlighted and summarised below.

Compiling national emissions: It is, at present, not possible to cross-check emissions estimates from this source category through external measurements. However, the inventory agency should ensure that emission estimates undergo quality control by:

- Cross-referencing aggregated crop yield and reported field area statistics with national totals or other sources of crop yield/area data;
- Back-calculating national emission factors from aggregated emissions and other data;
- Cross-referencing reported national totals with default values and data from other countries.

APPENDIX 4A.1
CH_4 AND N_2O EMISSIONS FROM SAVANNA BURNING: BASIS FOR FUTURE METHODOLOGICAL DEVELOPMENT

4A.1.1 Methodological issues

In savanna regions burning is carried out every one to several years. The burning results in instantaneous emissions of carbon dioxide (CO_2). As the vegetation regenerates between burning cycles, however, the CO_2 released into the atmosphere is reabsorbed during the next vegetation growth period. For this reason, net CO_2 emissions from savanna burning are assumed to be zero. Savanna burning also releases other trace gases, including CH_4, CO, NMVOCs, N_2O and NO_x. In this chapter, only emissions of the direct greenhouse gases CH_4 and N_2O are discussed.

4A.1.1.1 CHOICE OF METHOD

The choice of method depends upon the availability of activity data and emission factors for CH_4 and N_2O. If an inventory agency does not have activity data and emission factors, the default values in the *IPCC Guidelines* may be used.

The current method requires a value for the living fraction of aboveground biomass in Table 4-12 of the Workbook of the *IPCC Guidelines*. In addition, Table 4-13 of the *IPCC Guidelines* requires values for oxidised fraction and carbon fraction in living and dead biomass for calculating the amount of carbon and nitrogen released from savanna burning. These parameters are difficult to measure in the field. Combustion efficiency can be used to depict the vegetation and combustion conditions, which ultimately determine the emission factors of CH_4 and N_2O. The combustion efficiency is defined as the molar ratio of emitted CO_2 concentrations to the sum of emitted CO and CO_2 concentrations from savanna fires. A column for combustion efficiency is included in Table 4.A1 of this document. The compiled combustion efficiency data are derived from the results of biomass burning experiments in different savanna ecosystems in tropical America and Africa. Therefore, in the proposed method the revised equation for computing the amount of CH_4 or N_2O emitted per year would be:

EQUATION 4.A1

CH_4 OR N_2O RELEASED FROM SAVANNA BURNING

Amount of CH_4 or N_2O released = Amount of biomass burned (t dm) • Emission factor of CH_4 or N_2O (kg/t dm)

TABLE 4.A1 **AMOUNT OF ABOVEGROUND BIOMASS BURNED**				
Region	**Fraction of Total Savanna Burned Annually**	**Aboveground Biomass Density (t dm/ha)**	**Fraction of Biomass Actually Burned**	**Combustion Efficiency**
Tropical America	0.50	6.6±1.8	0.85	0.95
Campo limpo[a.b]	0.3-1.0	7.1±0.5	1.0	0.96
Campo sujo[a.b]	0.3-1.0	7.3±0.5	0.97	
Campo cerrado[a.b]	0.3-1.0	8.6±0.8	0.72	0.94
Cerrado sensu stricto[a.b]	0.3-1.0	10.0±0.5	0.84	0.94
Tropical Africa	0.75	6.6±1.6	0.86	0.94
Sahel zone	0.05-0.15	0.5-2.5	0.95	
North Sudan zone	0.25-0.50	2-4	0.85	
South Sudan zone	0.25-0.50	3-6	0.85	
Guinea zone	0.60-0.80	4-8	0.90-1.0	
Moist Miombo[c,d,e]	0.5-1.0	8.9±2.7	0.74±0.04	0.92
Semiarid Miombo[c,e]	0.5-1.0	5.1±0.4	0.88±0.02	0.91
Moist Dambo[c,d,e]	0.5-1.0	3.0±0.5	0.99±0.01	0.95
Fallow Chitemene[c,e]	0.1	7.3±0.7	0.71±0.05	0.96
Semiarid Woodland (South Africa)[c,e]	0.25-0.5	4.6±2.8	0.85±0.11	0.93

[a]Kauffman *et al.* (1994), [b]Ward *et al.* (1992), [c]Shea *et al.* (1996), [d]Hoffa *et al.*(1999), [e]Ward *et al.* (1996).

For regions not specifically listed, data are contained in Table 4-14 of the *IPCC Guidelines*, Reference Manual (same as Table 4-12 of the Workbook of the *IPCC Guidelines.)* This table provides the basic ecological zones according to the available savanna statistics. Table 4.A1 above contains additional savanna data for four ecological zones in tropical America and five ecological zones in tropical Africa, based on the results of field experiments in Brazil, Zambia, and South Africa.

If an inventory agency has the necessary data for the fraction of savanna area burned annually, the aboveground biomass density, and the fraction of biomass actually burned in each ecological zone, the amount of biomass burned can be calculated at a disaggregated level.

It is desirable to develop the seasonal-dependent activity data and the emission factors of CH_4 and N_2O from savanna burning in various savanna ecosystems in each country if data are available. Fewer savanna areas and a smaller percentage of aboveground biomass are burned in the early dry season than in the late dry season. Therefore, as the dry season progresses in different savanna ecosystems, it is critical to monitor (i) the fraction of burned savanna area; (ii) the aboveground biomass density; (iii) the percentage of the aboveground biomass burned; and (iv) combustion efficiency.

4A.1.1.2 CHOICE OF EMISSION FACTORS

For savanna fires, there is a linear negative correlation between the CH_4 emission factor and the combustion efficiency. The emission factor is high for a fire of low combustion efficiency. The relationship is similar regardless of the climatic zone, the herbaceous species, or the amount of aboveground biomass.

Table 4.A2 lists different combustion efficiencies and associated CH_4 emission factors. Once the combustion efficiency of a savanna fire is determined according to the ecological zone and the burning period, the

corresponding emission CH_4 factor should be used to calculate the amount of CH_4 released per year from savanna burning.

TABLE 4.A2

COMBUSTION EFFICIENCY AND CORRESPONDING CH_4 EMISSION FACTOR

Combustion Efficiency	CH_4 Emission Factor (kg/t dm)
0.88	4.2
0.90	3.4
0.91	3.0
0.92	2.6
0.93	2.3
0.94	1.9
0.95	1.5
0.96	1.1
Source: Ward *et al.* (1996).	

The emission of N_2O from biomass burning is linearly correlated with the emission of CO_2 and is dependent on the nitrogen content of the vegetation. The emission factor of N_2O is calculated by the equation:

EQUATION 4.A2

N_2O EMISSION FACTOR

Emission factor of N_2O (kg/t dm) = Emission factor of CO_2 (kg/t dm) • 1/Molecular weight of CO_2 • Molar emission ratio of N_2O to CO_2 • Molecular weight of N_2O

Equation 4.A2 is simplified to:

EQUATION 4.A3

N_2O EMISSION FACTOR

Emission factor of N_2O (kg/t dm) = Emission factor of CO_2 (kg/t dm) • Molar emission ratio of N_2O to CO_2

Since N_2O is not stable during storage of smoke samples, the molar emission ratio of N_2O to CO_2 has been derived from laboratory experiments in which different types of vegetation were burned (Hao *et al.*, 1991) and can be expressed by:

EQUATION 4.A4

MOLAR EMISSION RATIO OF N_2O TO CO_2

Molar emission ratio of N_2O to CO_2 = $1.2 \bullet 10^{-5}$ + [$3.3 \bullet 10^{-5}$ • Molar ratio of nitrogen to carbon (N/C) in the biomass]

Emission factors for N_2O in several savanna ecosystems have been tabulated in Table 4.A3 on the basis of the results of field measurements of CO_2 emissions and the N/C ratios of the biomass. The default emission factors for N_2O in tropical America and Africa are calculated by averaging the emission factors for the continent. If an inventory agency has data on the N/C ratio in the biomass and assumes the emission factor for CO_2 to be 1700 kg/t dm, the emission factor for N_2O can be calculated by the two Equations 4.A3 and 4.A4 above.

TABLE 4.A3 **EMISSION FACTORS OF N_2O IN VARIOUS SAVANNA ECOSYSTEMS**			
Region	**Emission Factor of CO_2 (kg/t dm)**	**N/C Ratio in Biomass (%)**	**Emission Factor of N_2O (kg/t dm)**
Tropical America	-	-	0.065
Campo limpo[a, b, c]	1745	0.60	0.055
Campo sujo[a, b, c]	1700	0.56	0.052
Campo cerrado[a, b, c]	1698	0.95	0.074
Cerrado sensu stricto[a, b, c]	1722	1.02	0.079
Tropical Africa	-	-	0.070
Moist Miombo[b, c, d]	1680	1.42	0.099
Semiarid Miombo[b, c, d]	1649	0.94	0.071
Moist Dambo[b, c, d]	1732	0.33	0.040
Fallow Chitemene[b, c, d]	1761	0.77	0.066
Semiarid Woodland	1699	0.98 ± 0.11	0.075
Source: [a]Ward *et al.* (1992), [b]Susott *et al.* (1996), [c]Hao *et al.* (1991), [d]Ward *et al.* (1996).			

4A.1.1.3 CHOICE OF ACTIVITY DATA

The activity statistics for each savanna ecosystem include the following values: the savanna area; the fraction of savanna area burned; the aboveground biomass density; the fraction of aboveground biomass burned; and the carbon and nitrogen content in the biomass. Other parameters (i.e. the fraction of living and dead biomass burned and the carbon/nitrogen fraction of living and dead biomass) have been removed here because of the complexities of collecting these data in the field. Since the emission factor for CH_4 can decrease by 50-75% as the burning season progresses, it is strongly suggested that each inventory agency collect seasonal data on the fraction of savanna area burned, the aboveground biomass density, and the fraction of aboveground biomass burned in each savanna ecosystem from the early dry season to the late dry season.

4A.1.1.4 DEVELOPING A CONSISTENT TIME SERIES

Since there is a large degree of uncertainty in determining the burned area in each savanna ecosystem, it may be useful to take an average of at least three years to provide a base year estimate for identification of any trend in the emissions of CH_4 and N_2O from savanna burning. The methods for ensuring a consistent time series are described in Chapter 7, Methodological Choice and Recalculation.

4A.1.1.5 UNCERTAINTY ASSESSMENT

The uncertainty of the emission factor for CH_4 is about ±20%, based on the results of extensive field experiments in tropical America and Africa. The uncertainty of the N_2O emission factor is also about ±20%, based on extensive laboratory experiments. The uncertainty of the aboveground biomass density in a savanna ecosystem ranges from ±2% to ±60%. The larger uncertainty is probably due to the variation of the composition of aboveground biomass at different sites. The uncertainty of the fraction of biomass actually burned is less than ±10%. Presently, it is difficult to estimate the uncertainty for the fraction of savanna area burned each year, or the amount of burning in, for example, the early and late season.

4A.1.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. The reporting in the worksheets contained in the *IPCC Guidelines* is transparent, however, the most critical issue in reporting and documentation is that majority of the activity data (e.g. the percentage of savanna area burned, the aboveground biomass density, and the fraction of biomass actually burned) are not available or are difficult to collect in the field. There are also no standard methods of collecting the information on area burned and fraction of biomass actually burned, resulting in inconsistency among the reported data.

4A.1.3 Inventory quality assurance/quality control (QA/QC)

As mentioned above, there are large degrees of uncertainty in the activity data to compute the amount of biomass burned in savanna. Very limited data are available on the seasonal trends of the savanna areas burned, the aboveground biomass densities, and the fractions of aboveground biomass burned. The monitoring of the locations of active savanna fires and the mapping of burned areas in each country can be improved by using the satellite imagery available from various national and international agencies. In addition, standard methods have to be developed to measure the aboveground biomass density, the fraction of biomass burned, and the combustion efficiency in order to ensure the quality and consistency of the data.

APPENDIX 4A.2
CH_4 AND N_2O EMISSIONS FROM AGRICULTURAL RESIDUE BURNING: BASIS FOR FUTURE METHODOLOGICAL DEVELOPMENT

Although the burning of agricultural residues is not considered a net source of carbon dioxide because the carbon released to the atmosphere is reabsorbed during the next growing season, this burning is a source of net emissions of many trace gases including CH_4, CO_2, N_2O, and NO_x. It is important to note that some agricultural residues are removed from the fields and burned as a source of energy, especially in developing countries. Non-CO_2 emissions from this type of burning are dealt with in the Energy sector of the *IPCC Guidelines*. Crop residue burning must be properly allocated to these two components in order to avoid double counting. The following discussions are focused only on the direct greenhouse gases CH_4 and N_2O.

4A.2.1 Methodological issues

4A.2.1.1 CHOICE OF METHOD

The choice of method will depend on the availability of activity data and emission factors for CH_4 and N_2O in each country. Where available, country-specific activity data and emission factors for CH_4 and N_2O should be used. If a country does not have its own activity data and emission factors, the default values in the *IPCC Guidelines* may be used instead.

The largest degree of uncertainty in estimating the emission inventories of CH_4 and N_2O from agricultural residue burning is the fraction of agricultural residue burned in the field. The percentage of residue burned on-site must be based on a complete mass balance accounting of the residue. For substantial improvement in the emission estimates of CH_4 and N_2O, inventory agencies are encouraged to estimate local and regional practices that reflect: (i) the fraction of residue burned in the field; (ii) the fraction transported off the field and burned elsewhere (associated with processing); (iii) the fraction consumed by animals in the field; (iv) the fraction decayed in the field; and (v) the fraction used by other sectors (e.g. biofuel, domestic livestock feed, building materials, etc.). Currently, it is estimated that 10% of the total agricultural residue is burned in the field in developed countries and 25% in developing countries. These figures may be too high. *Good practice* suggests that an estimate of 10% may be more appropriate for developing countries.

4A.2.1.2 CHOICE OF EMISSION FACTORS

The CH_4 and N_2O emission factors in Table 4.16 of the Workbook of the *IPCC Guidelines* are generally reasonable. There are also insufficient data to update these emission factors as few field experiments have been conducted in the past five years that measure emissions produced by burning agricultural residue in the field. Emission factors, however, are probably dependent on weather conditions in the burning periods, as the emission factor of CH_4 from savanna burning decreases from the early dry season to the late dry season. If an inventory agency is conducting experiments to measure the CH_4 and N_2O emission factors from burning agricultural residue, the experiments should be carried out in the dry season and rainy season when crop residue is burned.

4A.2.1.3 CHOICE OF ACTIVITY DATA

The activity data for crop production can be obtained from either the country's data or the *FAO Production Yearbook* (U.N. Food and Agriculture Organisation). These statistical data are reasonably accurate. There are few data available to update residue/crop ratios, dry matter fractions, carbon fractions, and nitrogen to carbon ratios for different crop residue. When an inventory agency is compiling its activity data, it is necessary to collect monthly weather data and data on the amount of each crop residue burned after harvest. Weather conditions would influence the combustion efficiency (see Appendix 4A.1 of this chapter) and the CH_4 and N_2O emission factors.

4A.2.1.4 COMPLETENESS

The current method incorporates all the factors necessary to estimate the CH_4 and N_2O emissions from burning agricultural residue. Several crops are missing in Table 4.15 of the Workbook of the *IPCC Guidelines* (e.g. sugarcane and root crops such as cassava and yam). The ratio of residue to crop is 0.16 for sugarcane and 0.4 for root crops. It is important to account for the entire disposition of agricultural residue in the mass balance. Residue not being burned in the field will become a source of CH_4 or N_2O from microbial decomposition, domestic energy consumption, and domestic waste. These sources will have to be incorporated into the computation of CH_4 and N_2O emissions from other activities.

4A.2.1.5 DEVELOPING A CONSISTENT TIME SERIES

There are good prospects for developing the trend of CH_4 and N_2O emissions from agricultural residue burning because the statistics of agricultural production are compiled with reasonable accuracy. The weakness in the computation is estimating the percentage of residue burned in the field. Each inventory agency has to collect activity data on disposition of each crop residue, especially the percentage of residue burned on-site, after harvest.

4A.2.1.6 UNCERTAINTY ASSESSMENT

Crop production data, including cash crops and subsistence farming, are reasonably accurate, although it is difficult to determine the uncertainty. The uncertainties in CH_4 and N_2O emission factors for burning agricultural residue in the dry season are about ±20%. It is not known, however, about the emission factors in the rainy season. The fraction of agricultural residue burned in the field is probably the variable with the largest degree of uncertainty in estimating the amount of CH_4 and N_2O emitted from agricultural residue burning. Statistical data have to be compiled to account for the use of agricultural residue after harvest.

4A.2.2 Reporting and documentation

It is *good practice* to document and archive all information required to produce the national emissions inventory estimates as outlined in Chapter 8, Quality Assurance and Quality Control, Section 8.10.1, Internal Documentation and Archiving. Agricultural production data are easily accessible from each country or the *FAO Production Yearbook*. Weather conditions and the amount of each crop burned in the field during the dry season and rainy season have to be reported. It is necessary to measure and report the dry matter fraction, the carbon fraction, and the nitrogen to carbon ratio for each crop residue. It is also important to conduct field experiments that measure the CH_4 and N_2O emission factors in the dry and rainy season.

4A.2.3 Inventory quality assurance/quality control (QA/QC)

The quality of CH_4 and N_2O emissions estimates from agricultural residue burning will vary considerably from country to country, depending largely on the quality of the data on the percentage of the residue burned in the field. The qualities of other activity data and emission factors are reasonable and can be improved by collecting the data of the amount of residue burned during the dry season and rainy season. Crop production data can be verified by using commodity trade statistics.

APPENDIX 4A.3 CH_4 EMISSIONS FROM RICE PRODUCTION: MEASUREMENT, REPORTING, AND QA/QC OF FIELD DATA

Conducting Field Measurement: A standardised control rice plot with at least three replicate fields should be used to obtain standard regional and country emission factors. Plots are to be kept flooded from shortly before transplanting until maturity. The experimental plots should not have a recent history (i.e. five years) of added organic amendments to the soil other than recycled roots and perhaps short stubble. CH_4 flux measurements should be recorded at least twice per week over an entire flooded season. In areas where double or triple rice cropping is practised, data should be collected for all growing seasons. For a guideline for *good practice* standardised measurements for the irrigated rice ecosystem, see IGAC (1994). The nature of the instrumentation and the frequency of measurement will determine the associated uncertainty. For typical measurements, the associated uncertainty is expected to be at least 20%.

The accuracy and precision of CH_4 emission estimates increases with both the number of sites tested and the frequency and number of measurements at each site.

Other data, such as the location and extent of area that the measurement represents, soil data, and climate information, should be collected. Agronomic data such as rice yield and other crop production data are also important because these data can be used to determine if measurements are representative of typical agronomic conditions. In general, the various predictive models that have been recently published (e.g. Huang *et al.*, 1998) may aid in reporting CH_4 emission values. *Good practice* is to provide as much country- or region-specific detail as is feasible.

Reporting of Field Measurements: The minimum data set that should accompany flux measurements for (i) scaling factor determination, (ii) verification of inventory using models and, (iii) QA/QC consists of:

- Geographic data including site country and province, latitude and longitude, average elevation, and a short description of the location;
- A data log of agricultural events (e.g. time of organic input application, water management, weeding, etc.), method of crop establishment and dates of important plant events (e.g. transplanting, heading, harvest date);
- Air and soil temperature at 5 cm depth taken at the time of each flux measurement;
- Fertiliser types, application rates (including chemical amendments), and timing and mode of application;
- Soil types classified according to USDA Soil Taxonomy or FAO/UNESCO Soil Classification, at least on subgroup levels. General soil characteristics, including texture, should be measured;
- Water management (number of flooding days, drainage/drought events);
- Impact of organic amendment on emissions (type and amount of amendment should be documented);
- Rice cultivar used (name, crop duration, height, traditional or modern variety, specific traits);
- Plant parameters preferably for different growth stages (e.g. leaf area index, above ground biomass (straw and stubble), yield, harvest index).

Field Measurement QA/QC: Country scientists will usually determine field-level QA/QC procedures to establish country-specific emission factors. To ensure the comparability and inter-calibration of extended data sets used to establish country-specific emission factors, there are certain internationally determined procedures to obtain 'standard emission factors' that should be common to all monitoring programs (see IGAC (1994), Sass (1999)):

(i) CH_4 flux measurements should be recorded at least *twice per week* over an entire flooded season.

(ii) In areas where double rice cropping (or 5 rice crops in 2 years) is practised, data should be collected for all growing seasons.

(iii) Manual sampling of flux chambers may miss the large fluxes of soil-entrapped CH_4 upon drainage. In such cases, a correction should be made. If no specific data are available, an estimated 10-20% increase of seasonal emission can be applied.

(iv) Significance of pre-planting emissions should be discussed and, if appropriate, estimated or measured.

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