CGE SUPPLEMENTARY TRAINING MATERIAL FOR THE TEAM OF TECHNICAL EXPERTS

Module 2.2c

Background material:

National greenhouse gas inventories – agriculture sector

Version	Date	Changes
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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

ABBREVIATIONS

CH_4	methane
CO	carbon monoxide
FAO	Food and Agriculture Organization of the United Nations
GHG	greenhouse gas
GPG 2000	*Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*
IPCC	Intergovernmental Panel on Climate Change
N	nitrogen
N_2O	nitrous oxide
NH_3	ammonia
NH_4	ammonium

1. BACKGROUND AND COURSE OBJECTIVES

This material was developed within the context of the process for international consultation and analysis to further support the training for the team of technical experts (TTE) and to provide additional background knowledge and context.

This module, prepared as supplementary training material to module 2.2 on technical analysis of greenhouse gas (GHG) inventories, aims to provide an overview of the methods and science involved in estimating emissions from the agriculture sector. This is intended for **those experts nominated to the UNFCCC roster of experts with no or limited prior knowledge and wishing to enhance their technical knowledge on national GHG inventories**.

It is drawn from the most recent Consultative Group of Experts (CGE) training materials on national GHG inventories for Parties not included in Annex I to the Convention (non-Annex I Parties), which are based on the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (hereinafter referred to as the Revised 1996 IPCC Guidelines), and *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (herein referred to as GPG 2000).

The information presented here should be further supplemented with that from the Revised 1996 IPCC Guidelines and GPG 2000 in order to address the complete length and breadth of science and methods involved in estimating GHG emissions from the agriculture sector.

2. SECTOR OVERVIEW

The Revised 1996 IPCC guidelines and the GPG 2000 provide guidance on categories of the agriculture sector. The activity level categories are enteric fermentation, manure management, rice cultivation, agricultural soils, prescribed burning of savannahs and field burning of agricultural residues.

Table 1
Greenhouse gas source and sink categories

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CH_4	N_2O	NO_x	CO	NMVOC
A. Enteric Fermentation					
1. Cattle [1]					
Option A:					
Dairy Cattle					
Non-Dairy Cattle					
Option B:					
Mature Dairy Cattle					
Mature Non-Dairy Cattle					
Young Cattle					
2. Buffalo					
3. Sheep					
4. Goats					
5. Camels and Llamas					
6. Horses					
7. Mules and Asses					
8. Swine					
9. Poultry					
10. Other *(as specified in table 4.A)*					
Other non-specified					
B. Manure Management					
1. Cattle [1]					
Option A:					
Dairy Cattle					
Non-Dairy Cattle					
Option B:					
Mature Dairy Cattle					
Mature Non-Dairy Cattle					
Young Cattle					
2. Buffalo					
3. Sheep					
4. Goats					
5. Camels and Llamas					
6. Horses					
7. Mules and Asses					
8. Swine					
9. Poultry					
10. Other livestock *(as specified in table 4.B(a))*					
Other non-specified					
11. Anaerobic Lagoons					
12. Liquid Systems					
13. Solid Storage and Dry Lot					
14. Other AWMS					
C. Rice Cultivation					
1. Irrigated					
2. Rainfed					
3. Deep Water					
4. Other *(as specified in table 4.C)*					
Other non-specified					
D. Agricultural Soils [2]					
1. Direct Soil Emissions					
2. Pasture, Range and Paddock Manure [3]					
3. Indirect Emissions					
4. Other *(as specified in table 4.D)*					
E. Prescribed Burning of Savannas					
F. Field Burning of Agricultural Residues					
1 . Cereals					
2. Pulses					
3 . Tubers and Roots					
4 . Sugar Cane					
5 . Other *(as specified in table 4.F)*					
Other non-specified					
G. Other *(please specify)*					
Other non-specified					

Source: IPCC.
Note: The grey cells indicate categories where emissions do not occur.

3. AGRICULTURE SECTOR EMISSION PROCESSES

3.1. ENTERIC FERMENTATION

Methane (CH_4) is a by-product of enteric fermentation, a digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream as a source of energy. CH_4 is produced during the process and may be released to the atmosphere. The amount of CH_4 produced and excreted by an individual animal is primarily dependent on the type of digestive system and the quantity and quality of feed consumed (which relates to the energy expenditure of the animal).

Ruminant animals have the highest emissions because of their specific digestive system and large microorganism populations in the rumen. Ruminant animals produce relatively higher emissions due to the presence of specific microorganisms in their digestive tracts that allow them to digest cellulose, a type of carbohydrate. The main ruminant animals are cattle, buffalo, goats, sheep and camels. Non-ruminants or pseudo-ruminant animals (e.g. horses, mules and asses) and monogastric animals (i.e. animals with one stomach such as swine) have relatively lower methane emissions because much less methane-producing fermentation takes place in their digestive systems. Generally, the CH_4 emission generation is a function of the quantity and the characteristics of the feed intake.

3.2. MANURE MANAGEMENT

CH_4 is also emitted from manure management practices. The emissions principally result from the decomposition of manure under anaerobic conditions, when manure is typically stored in large piles or disposed of in lagoons, where oxygen is absent or present in very low concentration. The anaerobic decomposition conditions are created when large numbers of animals are managed in a confined area (e.g. dairy farms, beef feedlots, and swine and poultry farms).

Nitrous oxide (N_2O), like CH_4 is also produced during the storage and treatment of manure before it is applied to land. Manure nitrogen is converted to N_2O through the activity of microorganisms during storage and treatment. The main manure treatment practices are anaerobic lagoons, liquid systems, solid storage and dry lot. The emissions of N_2O from manure depend on the nitrogen and carbon content of manure and on the duration of the storage and type of treatment.

N_2O emissions to the atmosphere from the land surface, due to the application of manure on soils are accounted for under “direct N_2O emissions from agricultural soils”. Unmanaged manure that is deposited directly on land by grazing animals is referred to as a “pasture, range and paddock” management system (i.e. animals grazing on pasture or grassland, animals that forage or are fed in paddocks and animals kept in pens around homes). N_2O emissions from manure of grazing animals occur directly and indirectly from the soil, and should be reported under “Pasture, range and paddock manure" for direct N_2O emissions, and under "Indirect emissions" for indirect N_2O emissions in agricultural soils.

3.3. RICE CULTIVATION

Anaerobic decomposition of organic material occurs in flooded rice cultivation fields leading to the generation of CH_4, which escapes to the atmosphere primarily by diffusion transport phenomena through the rice plants during the growing season. The process of release is ebullition (bubbles). The resulting fugitive emissions result in diffusion loss of CH_4 across the water surface. The level of emission is considered least significant in terms of the total emissions. Upland rice fields, which are not flooded, do not produce significant quantities of CH_4.

The amount of CH_4 emitted varies from one site to another due to various conditions, such as climatic conditions, number and duration of crops grown, soil type and texture, ecosystem type and water management practices (flooding pattern), and the use of fertilizers (sulphate containing amendments) and other organic and inorganic amendments. The parameters influence important factors that determine emissions such as the redox potential of the soil, soil temperature and the carbon substrate and nutrient availability.

3.4. AGRICULTURAL SOILS

N_2O is produced naturally in soils through the processes of nitrification and denitrification of inorganic nitrogen (N) in the soil. Nitrification is the aerobic microbial oxidation of ammonium to nitrate, and denitrification is the anaerobic microbial reduction of nitrate (NO_3-) to nitrogen gas (N_2). N_2O is generated as a gaseous intermediate in the reaction sequence of denitrification and a by-product of nitrification from microbial cells into the soil and ultimately into the atmosphere. The emissions of N_2O that result from anthropogenic N inputs or N mineralization occur through both a direct pathway (i.e. directly from the soils to which the N is added), and through two indirect pathways: (i) the volatilization of applied N as ammonia (NH_3) and oxides of nitrogen (NOx) followed by deposition as ammonium (NH_4) and NOx on soils and water; and (ii) the leaching and runoff of applied N in aquatic systems.

3.5. PRESCRIBED BURNING OF SAVANNAHS AND FIELD BURNING OF AGRICULTURAL RESIDUES

Agricultural residue burning releases gases which are by-products of incomplete combustion, namely: CH_4 and N_2O. Field (on-site) burning of crop residues, as an agricultural practice is used in many developing countries. However, burning of agricultural crop residues as an energy source should be covered in the energy sector.

4. METHODS TO ESTIMATE GREENHOUSE GAS EMISSIONS FROM THE AGRICULTURE SECTOR

4.1. INTRODUCTION

In the Revised 1996 IPCC Guidelines and GPG 2000, methods are generally referred to as 'tiers', with higher tier methods being more advanced. The GPG 2000 provides decision trees to help Parties in the selection of data and methods (i.e. tiers) for each individual category. These decision trees are intended to direct the Party to use the best method and data possible, given its national circumstances. In general, it is **good practice** for Parties to utilize higher tier methods, with their associated more detailed data, in particular for key categories. Parties are, however, permitted some flexibility in applying these decision trees as long as the choices made by the Party result in estimates that are of equivalent quality to those described in the GPG 2000.

This flexibility is an important characteristic of the Revised 1996 IPCC Guidelines and the GPG 2000 because it recognizes that parties have different national circumstances (e.g. availability of historical data). Although **good practice** is meant to direct Parties to use more rigorous methods and more detailed data, what is defined as 'good practice' can vary from Party to Party, depending on the national circumstances.

This section provides background on steps for estimating emissions in the agriculture sector, using the decision tree approach to select methods (appropriate tier level) consistent with national circumstances, emission factors and activity data. It also outlines consistent approaches to avoid double counting between categories in agriculture; and with categories in other sectors such energy, in accounting for non-CO_2 emissions from burning of agricultural residue for energy purposes.

4.2. LIVESTOCK CHARACTERIZATION

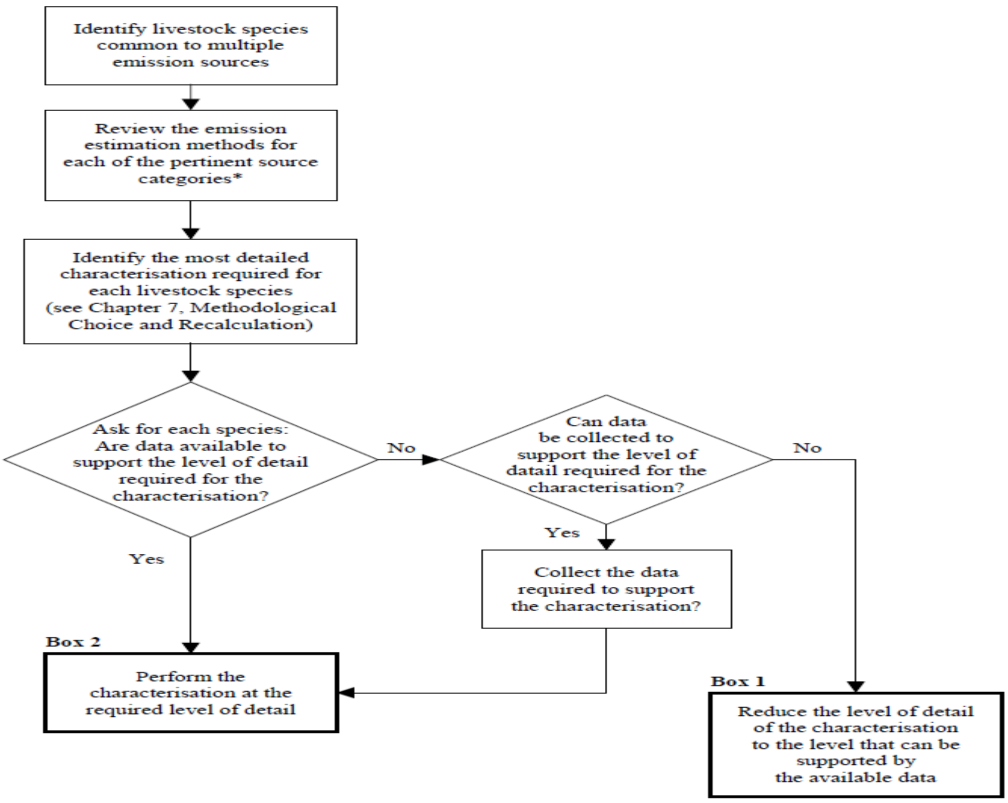
4.2.1. INTRODUCTION

Livestock characterization, categories and activity data are essential to the GHG inventories of CH_4 emissions from enteric fermentation, CH_4 and N_2O emissions from manure management, and N_2O emissions from agricultural soils. Good practice uses a single livestock population characterization as a framework for estimating CH_4 emissions from enteric fermentation, as well as CH_4 and N_2O emissions from manure management.

4.2.2. DECISION TREE FOR LIVESTOCK POPULATION CHARACTERIZATION

The Livestock Population Characterization section of GPG 2000[1] defines two approaches to livestock characterization: basic characterization and enhanced livestock characterization. It recommends the appropriateness of selected methods applied to each category depending on the significance of the individual subcategories determined by key category analysis. Figure 1 illustrates the decision tree for livestock characterization. The decision tree recommends tier 1 and tier 2 methods, defining the level of livestock population characterization.

Figure 1
Decision tree for livestock population characterization



*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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.9.

[1] GPG 2000, section 4.1.

4.2.3. BASIC CHARACTERIZATION

The basic activity data required are livestock characterization, livestock species and categories that determine choice of emission factors, and the annual animal population. The basic characterization for tier 1 is judged to be sufficient for most animal species in most countries. Good practice is to collect livestock characterization data: a list of livestock species and categories; and annual population data for each species and category,[2] including adjustments for seasonal variations and average annual milk production for dairy cows. If relevant, the percentage of animals in each of the climate regions defined in the Revised 1996 IPCC Guidelines should also be recorded. For dairy cattle, milk production should be used to estimate emission factors even if only a tier 1 method is used. The GPG 2000 provides detailed guidance on the activity data characteristics, summarized below:

4.2.3.1. Livestock species and categories

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

4.2.3.2. Annual livestock population

Inventory compilers should use population data from official national statistics or industry sources where available. However, data from the Food and Agriculture Organization of the United Nations (FAO) can be used if national data is unavailable. It is important to fully document the method used to estimate the annual population, including any adjustments to the original form of the population data as it was received from national statistical agencies or from other sources. Most animals in these growing populations are alive for only part of a complete year. Animals should be included in the populations regardless of whether they were slaughtered for human consumption or die of natural causes.

4.2.3.3. Dairy cows and milk production

The dairy cow population is estimated separately from other cattle.[3] Dairy cows are defined in this method as mature cows that are producing milk in commercial quantities for human consumption. The dairy cow category does not include cows kept principally to produce calves for meat or to provide draft power. Low productivity multipurpose cows should be considered as other cattle. Dairy buffalo may be categorized in a similar manner to dairy cows. Milk production data is used in

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[2] GPG 2000, p. 4.11, table 4.1: Representative cattle and buffalo categories, and table 4.2: Representative sheep categories.

[3] GPG 2000, p. 4.11, table 4.1.

estimating an emission factor for enteric fermentation using the tier 1 method.[4] Country-specific data sources are preferred, but FAO data may also be used.

4.2.3.4. 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 Revised 1996 IPCC Guidelines, three climate regions are defined in terms of annual average temperature: cool (<15°C), temperate (15°C–25°C), and warm (>25°C).[5] Livestock population data by region can be developed from country-specific climate maps.

4.2.4. ENHANCED CHARACTERIZATION

Enhanced livestock characterization includes detailed information on definitions for livestock subcategories, livestock population by subcategory and feed intake estimates for the typical animal in each subcategory. To use the tier 2 methods for enteric fermentation and manure management, enhanced livestock characterization must be specified.[6]

4.3. ENTERIC FERMENTATION

4.3.1. DECISION TREE FOR METHANE EMISSIONS FROM ENTERIC FERMENTATION

The GPG 2000 provides a decision tree for selecting the method for estimation of CH_4 from enteric fermentation, to help Parties select the appropriate tier based on their national circumstances (figure 2).

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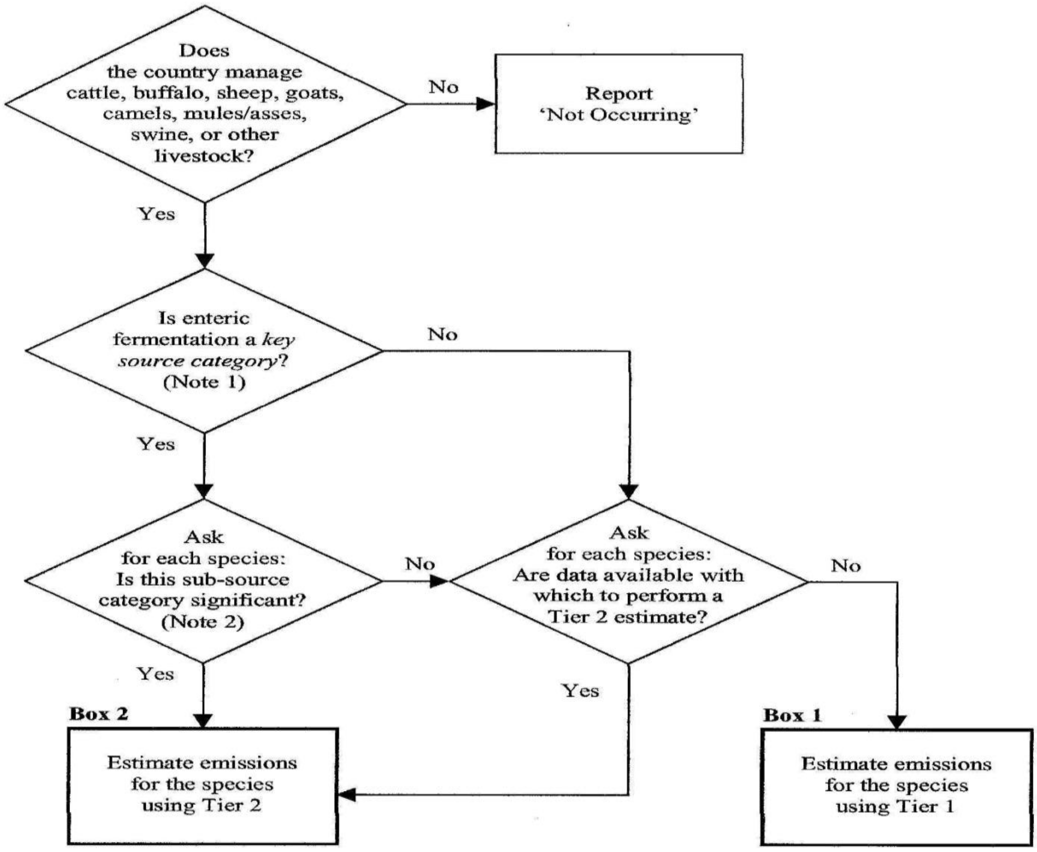
[4] GPG 2000, p. 4.15, table 4.4.
[5] Revised 1996 IPCC Guidelines, Reference Manual, table 4-1.
[6] For more information, see GPG 2000, p. 4.10.

Figure 2
Decision tree for methane emissions from enteric fermentation



Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.24.

4.3.1.1. Tier 1 method

Tier 1 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 all the animal species when the category is not a key source of emissions.

Under the tier 1 method, the animal population numbers and milk production by each animal categories defined in the basic characterization are the main activity data collected, when for the higher tier methods, feed intake and characterization are required. It is a good practice to select and use default emission factors for the estimation of the emissions. The Revised 1996 IPCC Guidelines provide default emission factors for each livestock category.[7]

[7] Revised 1996 IPCC Guidelines, Volume 3, Reference Manual, tables 4.3 and 4.4.

Equation 1
Emissions from a livestock category

EMISSIONS FROM A LIVESTOCK CATEGORY
$$\text{Emissions} = EF \bullet \text{population}/(10^6 \text{ kg/Gg})$$

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.25.

Equation 2
Total emissions from livestock

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.25.

Based on the equations above, the emission factor is multiplied by the animal population number 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 2.

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 Revised 1996 IPCC Guidelines and GPG 2000 provide detailed information for cattle and buffalo. Livestock experts should apply the values based on country circumstances. If the underlying characteristics are significantly different, the emission factors should be adjusted accordingly. If default enteric emission factors for livestock are used to estimate enteric emissions, a basic (tier 1) livestock population characterization is sufficient. It is a good practice, in characterizing livestock populations, to conduct a single characterization that will provide the activity data for all emission sources that depend on livestock population data.

4.3.1.2. Tier 2 methods

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 default values for the parameters are provided in the Revised 1996 IPCC Guidelines and GPG 2000.

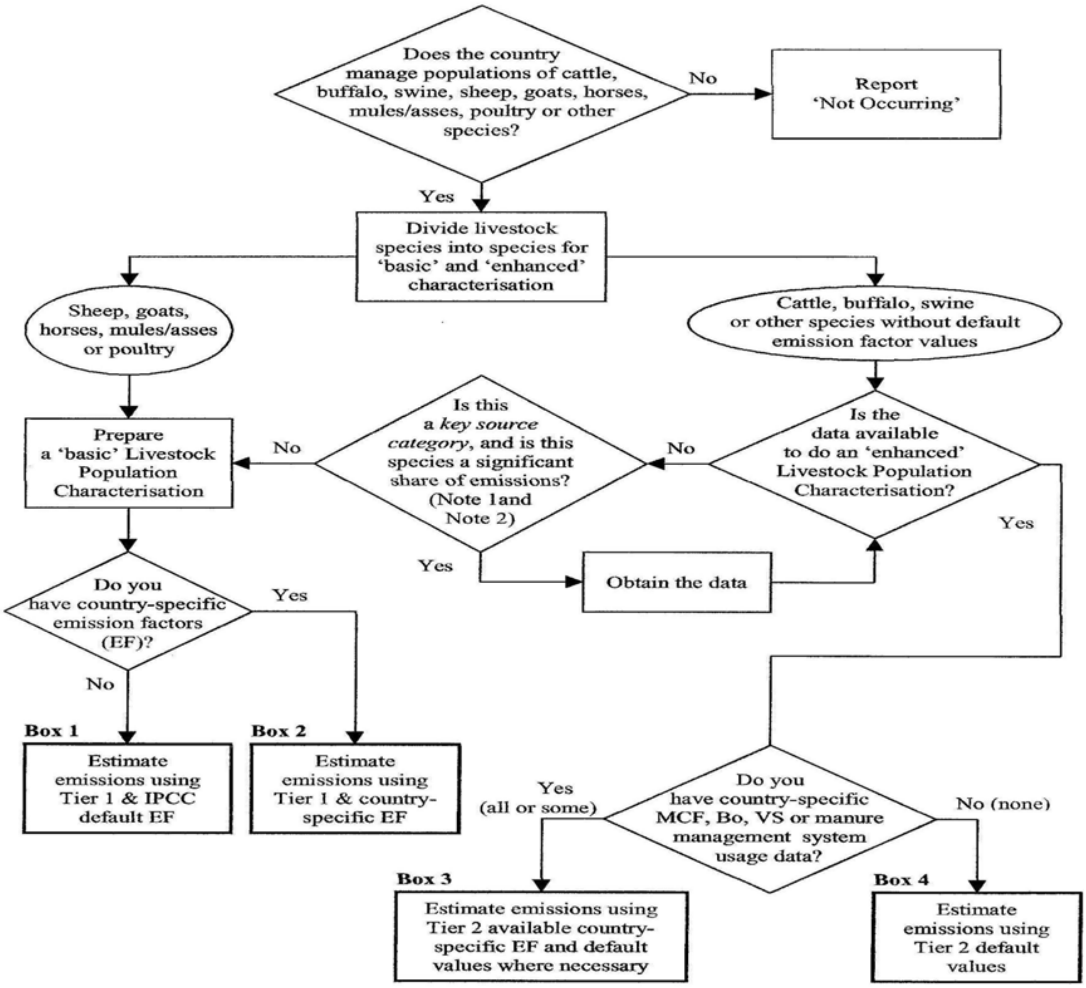
The tier 2 approach should be used if enteric fermentation is a key source category for the animal categories and represents a large portion of the country's total emissions.[8]

4.4. MANURE MANAGEMENT (METHANE)

4.4.1. DECISION TREE FOR METHANE EMISSIONS FROM MANURE MANAGEMENT

The GPG 2000 provides a decision tree for selecting the method for estimation of CH_4 emissions from manure management, to help Parties select the appropriate tier based on their national circumstances (figure 3).

Figure 3
Decision tree for methane emissions from manure management



Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.33.

[8] For more information, see GPG 2000, p. 4.25.

4.4.2. TIER 1 METHOD

The tier 1 approach is a simplified method that only requires livestock population data by animal species and category, and climate region (cool, temperate, warm), in order to estimate emissions.

It is a good practice to select and use default emission factors for the estimation of the emissions. The Revised 1996 IPCC Guidelines provide default emission factors for each livestock category.[9]

Equation 3
Methane emission from manure management

CH_4 EMISSION FROM MANURE MANAGEMENT
$CH_4\ Emissions_{(mm)} = Emission\ Factor \bullet Population\ /\ (10^6\ kg/Gg)$

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.30.

4.4.3. TIER 2 METHODS

The tier 2 approach provides a detailed method for estimating CH_4 emissions from manure management systems, and its use is encouraged for countries where a particular livestock species or 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 tier 2 approach uses the basis of manure characteristics (Bo, VS, MCF) to develop emission factors. The default values for some of the parameters are provided in the Revised 1996 IPCC Guidelines and GPG 2000.[10]

4.5. MANURE MANAGEMENT (NITROUS OXIDE)

4.5.1. DECISION TREE FOR NITROUS OXIDE EMISSIONS FROM MANURE MANAGEMENT

The GPG 2000 provides a decision tree for selecting the method for estimation of N_2O emissions from manure management, to help Parties select the appropriate tier based on their national circumstances (figure 4).

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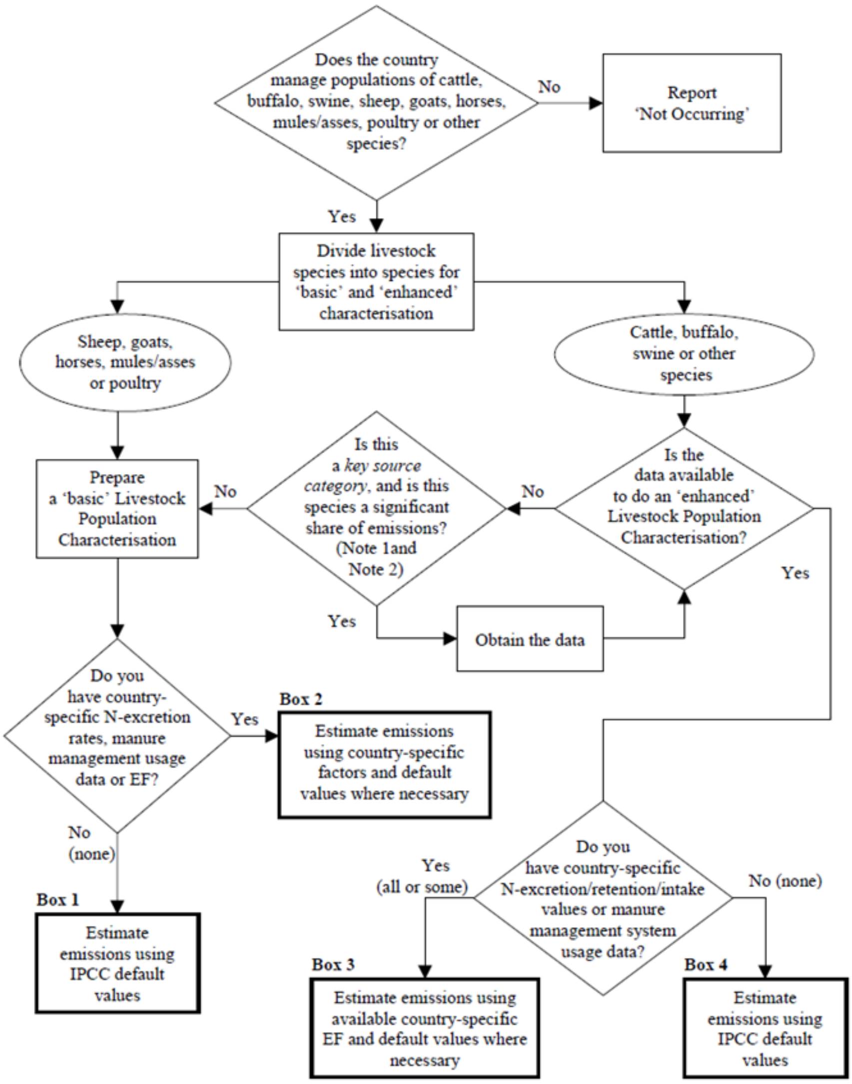
[9] Revised 1996 IPCC Guidelines, Volume 3, Reference Manual, tables 4.5 and 4.6.
[10] For more information, see GPG 2000, p. 4.31.

Figure 4
Decision tree for nitrous oxide 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.

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.41.

4.5.2. ESTIMATING EMISSIONS USING DEFAULT VALUES

The calculation of N_2O emissions from manure management is based on equation 4. The Revised 1996 IPCC Guidelines method for estimating N_2O emissions from manure management entails multiplying the total amount of N excretion (from all animal species and 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. To estimate emissions from manure management systems, the animal population must first be divided into species or categories that reflect the varying amounts of manure produced per animal, as well as the manner in which the manure is handled.

Equation 3
Nitrous oxide emissions from manure management

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:

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.42.

Emission factors

Default emission factors are presented in GPG 2000, tables 4.12 and 4.13.

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

Accurate annual nitrogen excretion rates should be determined for each animal species and category defined by the livestock population characterization. In some situations, it may be appropriate to utilize 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 Intergovernmental Panel on Climate Change (IPCC) default excretion rates should be used.[11] 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 GPG 2000, table 4.14.

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 that used to estimate CH_4 emissions from manure management. If country-specific manure management system usage data is not available, default values from the Revised 1996 IPCC Guidelines should

[11] Revised 1996 IPCC Guidelines, Reference Manual, p. 4.99, table 4-20.

be used. The IPCC default values for dairy cattle, non-dairy cattle, buffalo and swine should be taken from the Revised 1996 IPCC Guidelines, Reference Manual, Agriculture chapter, section 4.2 (Livestock), appendix B, tables B-3 through B-6. The IPCC default values for all other animal species and categories should be taken from table 4-21.

4.5.3. ESTIMATING EMISSIONS USING COUNTRY-SPECIFIC FACTORS

It is desirable to use country-specific emission factors and parameters, for example $Nex_{(T)}$, to reflect the national circumstances and the actual duration of storage and type of treatment of animal manure in each management system that is used. The method is the same as for estimating emissions using the IPCC default values.[12]

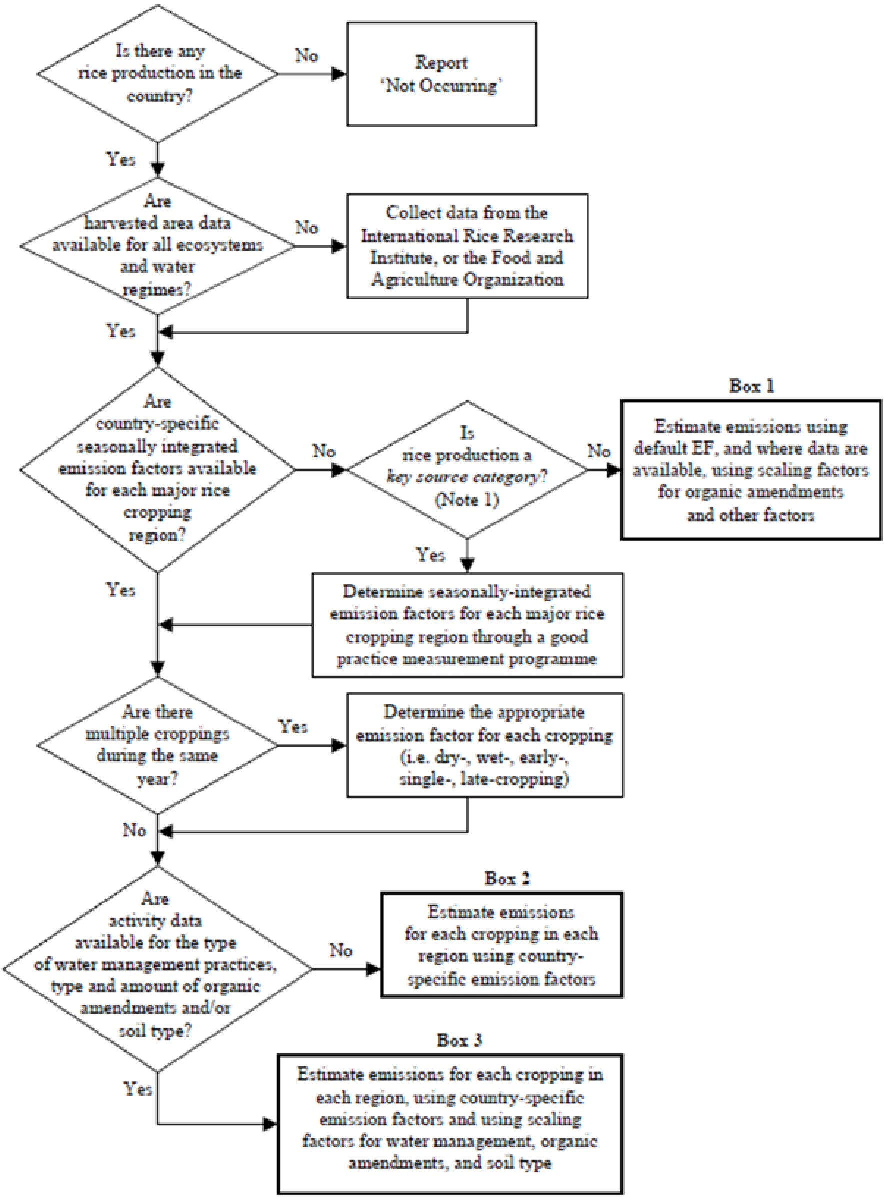
4.6. RICE CULTIVATION

4.6.1. DECISION TREE FOR METHANE EMISSIONS FROM RICE PRODUCTION

The GPG 2000 provides a decision tree for selecting the method for estimation of CH_4 emissions from rice production, to help Parties select the appropriate tier based on their national circumstances (figure 5).

[12] For more information, see GPG 2000, p. 4.42.

Figure 5
Decision tree for methane emissions 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.)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p.4.79.

4.6.2. ESTIMATING EMISSIONS USING DEFAULT EMISSION FACTORS

The Revised 1996 IPCC Guidelines and GPG 2000 provide one method for estimating methane emissions from rice production (equation 5). This method uses annual harvested areas and area-based seasonally integrated emission factors. In its simplest 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 in which rice is grown (e.g. water management practices, organic fertilizer use and soil type) may be highly variable and may significantly affect CH_4 emissions. The IPCC method can be modified to account for this variability in growing conditions by disaggregating national total harvested area into subunits (e.g. harvested areas under different water management regimes) and multiplying the harvested area for each subunit by an emission factor that is representative of the conditions that define the subunit.

Equation 4
Methane emissions from rice production

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)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.77.

Activity data

Data on rice cultivation under different water management techniques should be available from most of the important rice-producing countries. Therefore, the basic method for estimating emissions from each country includes estimates based on rice ecosystems. The key water ecosystems identified in the Revised 1996 IPCC Guidelines are presented in table 2.

Table 2
Water ecosystems

Box 4.5.9	
Water ecosystem	**Characteristics**
Upland	Fields are never flooded for a significant period of time.
• **Lowland**:	Fields are flooded for a significant period of time.
• **Irrigated**:	Water regime is fully controlled.
• **Continuously flooded:**	Fields have standing water throughoutthe rice growing season and may only dry for harvest.
• **Intermittently flooded :**	Fields have at least one aeration period ofmore than 3 days during the cropping season.
• **Single aeration:**	Fields have a single aeration during thecropping season at any growth stage
• **Multiple aeration:**	Fields have more than one aerationperiod during the cropping season.
• **Rainfed**:	Water regime depends solely on precipitation.
• **Flood prone:**	The water level may rise up to 50 cm during thecropping season.
• **Drought prone**:	Drought periods occur during every croppingseason.
• **Deep water rice**:	Floodwater rises to more than 50 cm for a significant
	period of time during the cropping season.
	period of time during the cropping season.
	· Fields inundated with water depth from 50-100 cm.
	· Fields inundated with water depth > 100 cm.

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.

GPG 2000 provides an equation to calculate the seasonally integrated emission factor (equation 6):

Equation 5
Adjusted seasonally integrated emission factor

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.80.

The seasonally integrated emission factor for continuously flooded fields of major soil types without organic amendments (EF_c) should be determined through field measurements according to good practice procedures.[13] If data to determine EF_c is not yet available, the IPCC default of 20 g/m^2 may be used.

Scaling factors can be used to adjust the EF_c to account for the various conditions discussed in figure 6. In order, the three most important scaling factors are rice ecosystem and 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.

Figure 6
Considerations for rice production emission factor development

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.

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.78.

Water management system

The main types of methane-emitting rice ecosystems are irrigated, rain-fed 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 in GPG 2000 provides IPCC default scaling factors for differences in ecosystem and water management regime 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.

[13] As discussed in GPG 2000, Appendix 4A.3, p. 4.91.

Organic amendments

Good practice is to develop a scaling factor 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 in GPG 2000 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 parties 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.

Soil types

In some cases emission data for different soil types are available and can be used to derive scaling factors for soil types. The major motivation to incorporate soil type as a scaling factor is that both experiments and mechanistic knowledge confirm its importance.

4.6.3. ESTIMATING EMISSIONS USING COUNTRY-SPECIFIC EMISSION FACTORS

It is desirable to use country-specific emission factors to reflect the conditions of rice cultivation, for example rice ecosystem type, water management regime, type and amount of organic amendments, and soil type. The method is the same as for estimating emissions using the default emission factor.[14]

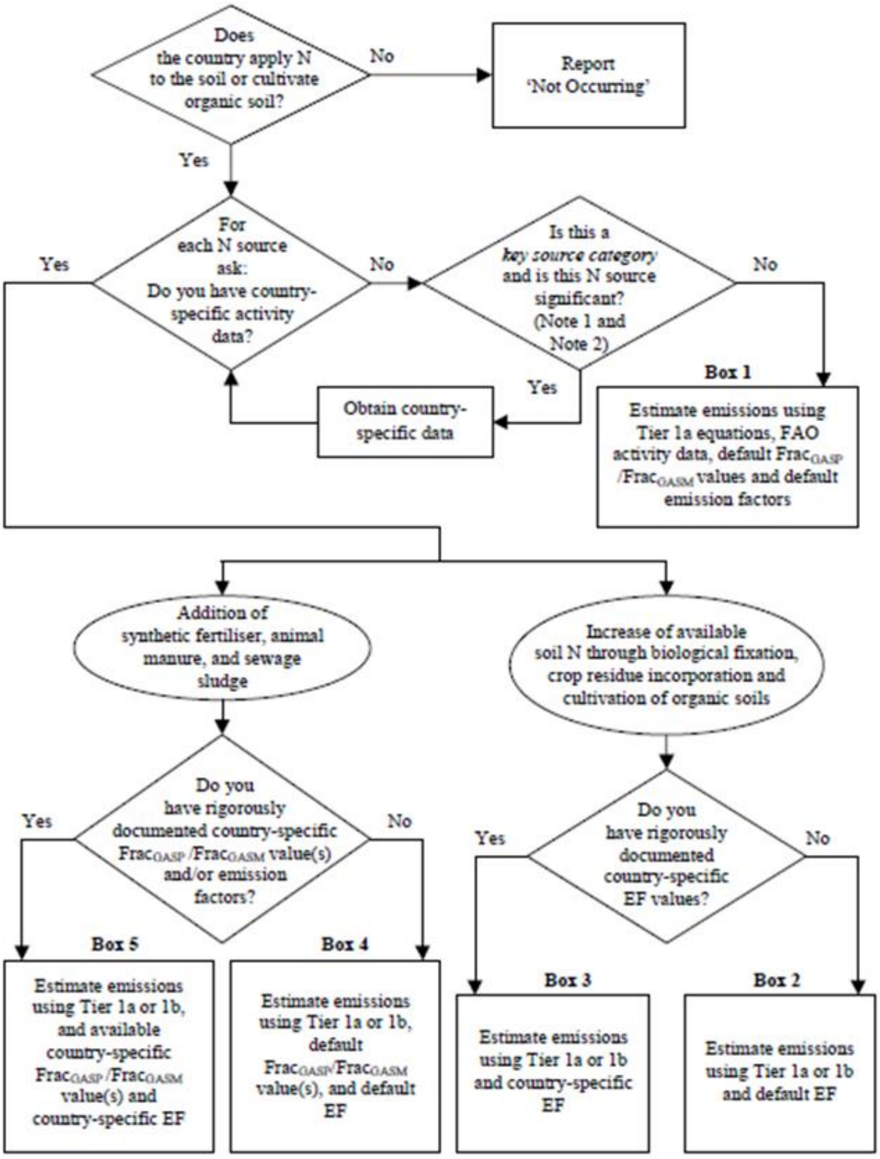
4.7. AGRICULTURAL SOILS: DIRECT NITROUS OXIDE EMISSIONS

4.7.1. DECISION TREE FOR DIRECT NITROUS OXIDE EMISSIONS FROM AGRICULTURAL SOILS

The GPG 2000 provides a decision tree for selecting the method for estimation of direct N_2O emissions from agricultural soils, to help Parties select the appropriate tier based on their national circumstances (figure 7).

[14] For more information, see GPG 2000, p. 4.80.

Figure 7
Decision tree for direct nitrous oxide 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.

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.55.

The significant sources of anthropogenic nitrogen inputs resulting in direct N_2O emissions from agricultural soils are: a) application of synthetic fertilizers; b) application of animal manure; c) cultivation of nitrogen-fixing crops; d) incorporation of crop residues into soils; e) soil nitrogen mineralization due to cultivation of organic soils; and (f) other sources such as sewage sludge, which should be included if sufficient information is available.

The estimation of direct N_2O emissions from pasture, range and paddock manure, is covered in N_2O emissions from manure management. 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. Calculation method

The GPG 2000 decision tree for direct nitrous oxide emissions from agricultural soils recommends only one tier for this source category, but with two variations: tier 1a and tier 1b, which include updated equations. The selection of a tier 1a or tier 1b method is not related to the key source condition but to the availability of activity data. Preference should be given to the tier 1b equations, which expand the number of terms in the equations. For Parties without the necessary data for tier 1b, the simpler tier 1a equations are acceptable. Estimating emissions combining tier 1a and tier 1b equations for different subcategories, depending on the availability of activity data, is also acceptable. For some subcategories there are no tier 1b equations because no refinement was considered. The use of equation 7 (4.20) is considered tier 1a.

Equation 6
Direct nitrous oxide emissions from agricultural soils (tier 1a)

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:

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.54.

Several types of activity data are required for this source category and it is highly unlikely that the Party will be able to fulfil all the requirements because many of the data types are beyond the scope of the national statistics collection system. Due to the importance of this source, it is desirable that the Parties make their best efforts to have country-specific activity data. The IPCC method requires various activity data and emission factors.

4.7.1.2. Activity data

Synthetic fertilizer nitrogen (F_{SN})

The term F_{SN} refers to the annual amount of synthetic fertilizer nitrogen applied to soils after adjusting to account for the amount that volatilizes. It is estimated by determining the total amount of synthetic fertilizer consumed annually (N_{FERT}), and then adjusting this amount by the fraction that volatilizes as NH_3 and NO_x ($Frac_{GASF}$). This is set out in equation 8.

Equation 7
Nitrogen from synthetic fertilizer application

N FROM SYNTHETIC FERTILISER APPLICATION

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.56.

The default value of $Frac_{GASF}$ is 10 per cent, which is presented in table 4-19 in the Revised 1996 IPCC Guidelines, Reference Manual. However, the loss rate can be highly variable, and depends on the type of synthetic fertilizer applied, the mode of application and climate. The use of appropriately documented country-specific loss rates is encouraged.

Animal manure nitrogen used as fertilizer (F_{AM})

The term F_{AM} refers to the amount of animal manure nitrogen intentionally applied to soils after adjusting to account for the amount that volatilizes. It is estimated by determining the total amount of animal manure nitrogen produced annually ($\Sigma T(N_{(T)} \bullet Nex_{(T)})$), and then adjusting this amount to account for the animal manure that is burned for fuel ($Frac_{FUEL-AM}$), deposited onto soils by grazing livestock ($Frac_{PRP}$) and volatilized as NH_3 and NO_x ($Frac_{GASM}$). For this calculation, the equation presented in the Revised 1996 IPCC Guidelines is replaced equation 9.

Equation 8
Nitrogen from animal manure application

N FROM ANIMAL MANURE APPLICATION

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.56.

The value of $N_{(T)}$ and $Nex_{(T)}$ must be consistent with the category of manure management.

Default value of $Frac_{GASM}$ is 20 per cent, which is presented in table 4-19 in the Revised 1996 IPCC Guidelines, Reference Manual. 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 fertilizer (represented by $Frac_{FUEL-AM}$, $Frac_{PRP}$) 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.

Nitrogen fixed by crops (F_{BN})

The approach presented in the Revised 1996 IPCC Guidelines for estimating the amount of nitrogen fixed by N-fixing crops cultivated annually (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 Revised 1996 IPCC Guidelines also assume that the mass ratio of residue to product is 1 (i.e. the total aboveground plant biomass is two 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 Revised 1996 IPCC Guidelines is illustrated in equation 10.

Equation 9
Nitrogen fixed by crops (tier 1a)

N FIXED BY CROPS (TIER 1A)

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.57.

The default values for $Frac_{NCRBF}$ for some crop types are presented in Table 4.16 in GPG 2000. 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 for N-fixing that is listed in the Revised 1996 IPCC Guidelines, Reference Manual, table 4-19, can be used (0.03 kg N/kg dry matter).

Nitrogen in crop residues returned to soils (F_{CR})

In the Revised 1996 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 ($Frac_R$) and burned ($Frac_{BURN}$). The tier 1a equation presented in the Revised 1996 IPCC Guidelines is illustrated in equation 11.

Equation 10
Nitrogen in crop residue returned to soils (tier 1a)

$$\text{N IN CROP RESIDUE RETURNED TO SOILS (TIER 1a)}$$
$$F_{CR} = 2 \bullet (Crop_O \bullet Frac_{NCRO} + Crop_{BF} \bullet Frac_{NCRBF}) \bullet (1 - Frac_R) \bullet (1 - Frac_{BURN})$$

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.58.

Default values for $Frac_{NCRO}$ and $Frac_{NCRBF}$ for some crop types are presented in table 4.16 in GPG 2000. 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 the Revised 1996 IPCC Guidelines, Reference Manual, table 4-19, can be used (0.03 and 0.015 kg N/kg dry matter, respectively).

The default value for $Frac_R$ and $Frac_{BURN}$ are provided in the Revised 1996 IPCC Guidelines, Reference Manual, table 4-19.

Area of organic soils harvested (F_{OS}). The Revised 1996 IPCC Guidelines define 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.

4.7.1.3. 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. 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 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 Parties will use a mix of default values and country-specific emission factors when the latter do not cover the full range of environmental and management conditions. The good practice default emission factors are summarized in GPG 2000, table 4.17.

4.7.2. TIER 1B METHOD

The tier 1b equation is expanded from the tier 1a equation to estimate emissions in more detail.[15]

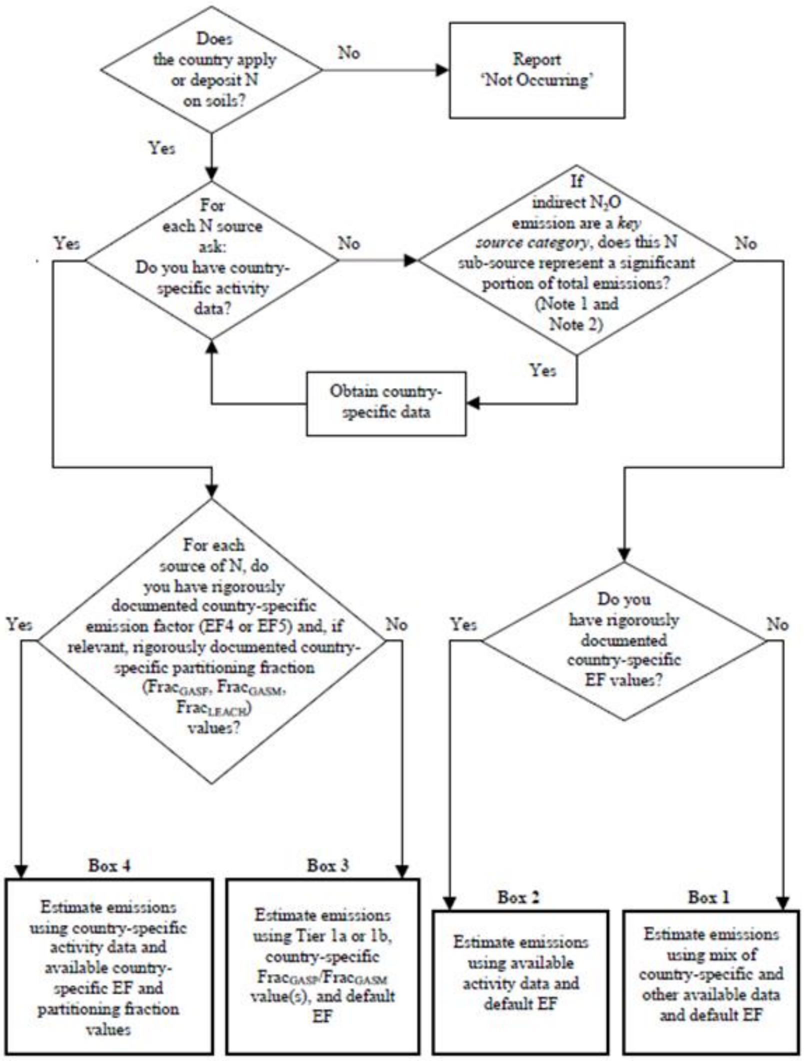
[15] For more information, see GPG 2000, p. 4.56.

4.8. AGRICULTURAL SOILS: INDIRECT NITROUS OXIDE EMISSIONS

4.8.1. DECISION TREE FOR INDIRECT NITROUS OXIDE EMISSIONS FROM NITROGEN USED IN AGRICULTURE

The GPG 2000 provides a decision tree for selecting the method for estimation of indirect N_2O emissions from nitrogen used in agriculture, to help Parties select the appropriate tier based on their national circumstances (figure 8).

Figure 8
Decision tree for indirect nitrous oxide 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.

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.69.

4.8.2. TIER 1A METHOD

4.8.2.1. Calculation method

The method in the Revised 1996 IPCC Guidelines for estimating indirect N_2O emissions from N used in agriculture describes three separate pathways:

- Atmospheric deposition on soils of NO_x and NH_4 with the sources of N including volatilization of N inputs to soils, as well as combustion and industrial process sources;
- Leaching and run-off of N that is applied to, or deposited on, soils;
- Disposal of sewage N.

The basic equation shown in the Revised 1996 IPCC Guidelines for estimating a country's indirect N_2O emissions (N_2Oindirect) (kg N/year) illustrated in equation 12.

Equation 11
Indirect nitrous oxide emissions

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

$N_2O_{(G)}$ = 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:

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.67.

The GPG 2000 decision tree recommends two variations in the method for estimating indirect N_2O emissions (tier 1a and tier 1b) as with estimating direct N_2O emissions.

Atmospheric deposition ($N_2O_{(G)}$)

Atmospheric deposition of nitrogen compounds, such as NO_x and NH_4, fertilizes soils and surface waters, which results in enhanced biogenic N_2O formation. According to the Revised 1996 IPCC Guidelines, the amount of applied agricultural N that volatilizes and subsequently deposits on nearby soils is equal to the total amount of synthetic fertilizer nitrogen applied to soils (N_{FERT}) plus the total amount of animal manure N excreted in the country ($\Sigma T(N_{(T)} \bullet Nex_{(T)})$) multiplied by appropriate volatilization factors. The volatilized N is then multiplied by an emission factor for atmospheric deposition (EF_4) to estimate $N_2O_{(G)}$ emissions. This is illustrated in equation 13.

Equation 12
Nitrous oxide from atmospheric deposition of nitrogen (tier 1a)

N_2O FROM ATMOSPHERIC DEPOSITION OF N (TIER 1a)

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

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]

$\Sigma_T(N_{(T)} \bullet Nex_{(T)})$ = 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

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.68.

The IPCC default emission factors are presented in GPG 2000, table 4.18.

Activity data and default parameters are consistent with those of the category of direct N_2O emissions.

Leaching and run-off 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 Revised 1996 IPCC Guidelines, the total amount of synthetic fertilizer 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 run-off ($Frac_{LEACH}$). N_{LEACH} is then multiplied by the emission factor for leaching and run-off (EF_5) to obtain emissions of N_2O in units of N, $N_2O_{(L)}$. This is illustrated in equation 14.

Equation 13
Deposited nitrogen from leaching and run-off

DEPOSITED N FROM LEACHING/RUNOFF[23]

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.71.

The IPCC default emission factors are presented in table 4.18 in GPG 2000.

Activity data and default parameters except $Frac_{LEACH}$ are consistent with those of the category of direct N_2O emissions.

For $Frac_{LEACH,}$ a default value of 30 per cent is presented in the Revised 1996 IPCC Guidelines, Reference Manual, table 4-24.

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 Revised 1996 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 N (N_{SEWAGE}) using the method in the Revised 1996 IPCC Guidelines, 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 N ($Frac_{NPR}$). 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 ($N_2O_{(S)}$). This is illustrated in equation 15.

Equation 14
Nitrous oxide emissions from discharge of sewage

N_2O EMISSIONS FROM DISCHARGE OF SEWAGE[27]

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

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.72.

The IPCC default emission factors are presented in table 4.18 in GPG 2000.

For $Frac_{NPR}$, a default value of 16 per cent is presented in the Revised 1996 IPCC Guidelines, Reference Manual, table 4-24, for the fraction of animal and plant protein that is N.

Much of the activity data required to estimate indirect N_2O emissions, such as fertilizer consumption and livestock N excretion, will have been previously developed for estimating emissions from other source categories. Table 4.19 in GPG 2000, Data for Estimating Indirect N_2O, summarizes the key activity data required, and describes where to obtain it (see table 3 below). It is essential that the same data sets be used across source categories to ensure consistency in emission estimates. As table 3 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. Table 3 summarizes good practice for developing the activity data.

Table 3
Data for estimating indirect nitrous oxide

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
$Frac_{FUEL-AM}$	From estimate of $Frac_{FUEL-AM}$ value collected for Direct N_2O Emissions from Agricultural Soils
$Frac_{FEED-AM}$	From estimate of $Frac_{FEED-AM}$ value collected for Direct N_2O Emissions from Agricultural Soils
$Frac_{CNST-AM}$	From estimate of $Frac_{CNST-AM}$ value collected for Direct N_2O Emissions from Agricultural Soils

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.74.

4.8.3. TIER 1B METHODS

The tier 1b equation is expanded from the tier 1a equation to estimate emissions in more detail.[16]

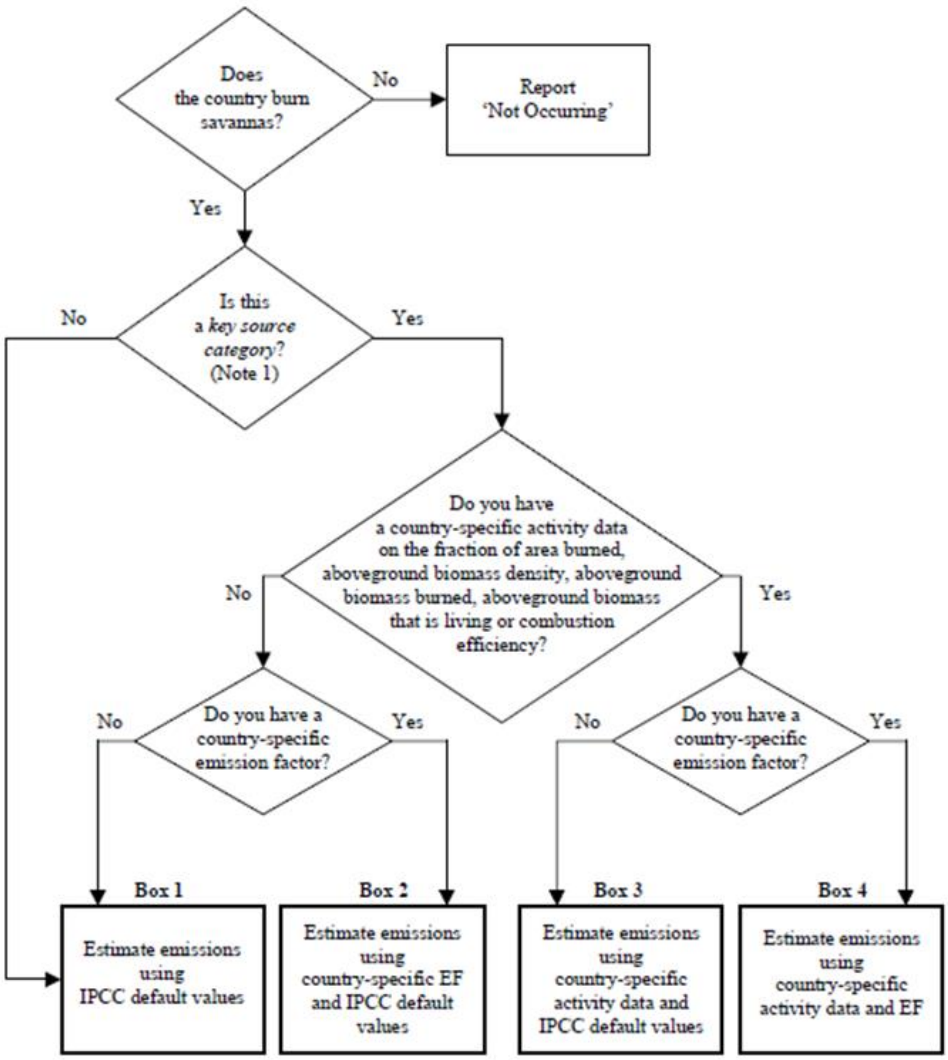
4.9. PRESCRIBED BURNING OF SAVANNAHS

4.9.1. DECISION TREE FOR METHANE AND NITROUS OXIDE EMISSIONS FROM SAVANNAH BURNING

The GPG 2000 provides a decision tree for selecting the method for estimation of CH_4 and N_2O emissions from savannah burning, to help Parties select the appropriate tier based on their national circumstances (figure 9).

[16] For more information, see GPG 2000, p. 4.68.

Figure 9
Decision tree for methane and nitrous oxide emissions from savannah 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.)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, *p. 4.50.*

4.9.2. ESTIMATING EMISSIONS USING DEFAULT VALUES

4.9.2.1. The Revised 1996 IPCC Guidelines method

The method for estimating CH_4 and N_2O emissions from burning of savannahs using default values, as set out in the Revised 1996 IPCC Guidelines Reference Manual requires: a value for the living fraction of aboveground biomass; values for the oxidized fraction after burning; and the carbon fraction of living and dead biomass, used to calculate the amount of carbon and nitrogen released from savannah burning. These parameters are difficult to measure in the field, and they are not usually included in the statistics collection systems, so national expert judgment is often necessary. Default values are provided in the Revised 1996 IPCC Guidelines, Reference Manual, table 4.14.

Box

Methane and nitrous oxide emissions from burning of savannahs

EQUATION 1

Area of Savanna Burned Annually (ha)

=

Total Area of Savanna (ha) x Fraction Burned Annually

EQUATION 2

Biomass Burned (t dm)

=

Area of Savanna Burned Annually (ha)
x Aboveground Biomass Density (t dm/ha) x Fraction Actually Burned

EQUATION 3

Carbon Released from Live Biomass (t C)

=

Biomass Burned (t dm) x Fraction that is Live x Fraction Oxidised
x Carbon Content of Live Biomass (t C/t dm)

EQUATION 4

Carbon Released from Dead Biomass (t C)

=

Biomass Burned (t dm) x Fraction that is Dead x Fraction Oxidised
x Carbon Content of Dead Biomass (t C/t dm)

EQUATION 5

Total Carbon Released (t C)

=

C Released from Live Material (t C) + C Released from Dead Material (t C)

The non-CO_2 trace gas emissions calculations from burning are summarised as follows:

CH_4 Emissions = (carbon released) x (emission ratio) x 16/12

CO Emissions = (carbon released) x (emission ratio) x 28/12

N_2O Emissions = (carbon released) x (N/C ratio) x (emission ratio) x 44/28

NO_x Emissions = (carbon released) x (N/C ratio) x (emission ratio) x 46/14

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 4.78-4.79.

The default CH_4 and N_2O emission factors are presented in the Revised 1996 IPCC Guidelines, Reference Manual, table 4.15.

4.9.2.2. The GPG 2000 method

Additional information on estimating CH_4 and N_2O emissions from burning of savannahs is provided in Annex 4A.1 of GPG 2000, which describes some of the details of a possible future revision of the methodology. The GPG 2000 equation is illustrated below (equation 16). The calculation method is different from that of the Revised 1996 IPCC Guidelines.

Equation 15
Methane or nitrous oxide released from savannah burning

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)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.84.

The default CH_4 and N_2O emission factors are presented in GPG 2000, table 4.A2 and table 4.A3.

Default parameters, 'fraction of total savannah burned annually', 'aboveground biomass density' (t dm/ha), 'fraction of biomass actually burned' and 'combustion efficiency', are presented in GPG 2000, table 4.A1.

4.9.3. ESTIMATING EMISSIONS USING COUNTRY-SPECIFIC VALUES

It is desirable to use country-specific values to reflect the national circumstances. The method is the same for estimating emissions using default values.[17]

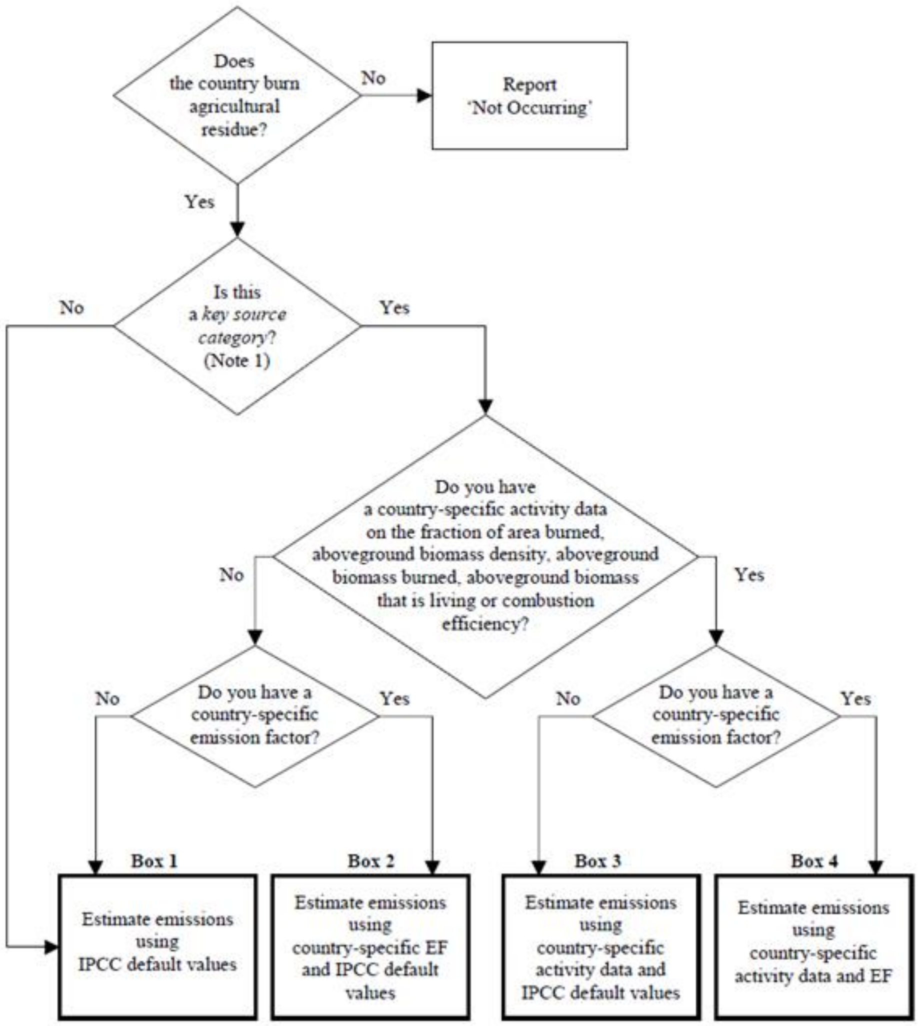
4.10. FIELD BURNING OF AGRICULTURAL RESIDUES

4.10.1. DECISION TREE FOR METHANE AND NITROUS OXIDE EMISSIONS FROM AGRICULTURAL RESIDUE BURNING

The GPG 2000 provides a decision tree for selecting the method for estimation of methane and nitrous oxide emissions from agricultural residue burning, to help Parties select the appropriate tier based on their national circumstances (figure 10).

[17] For more information, see GPG 2000, p. 4.84.

Figure 10
Decision tree for methane and nitrous oxide emissions from agricultural residue



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.)

Source: Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p. 4.52.

4.10.2. ESTIMATING EMISSIONS USING DEFAULT VALUES

Only one IPCC method is available to estimate non-CO_2 gas emissions from agricultural residue burning. When available, country-specific activity data and emission factors should be used. Default activity data and emission factors are available in the Revised 1996 IPCC Guidelines; in addition, the FAO database may help with data on surface of crops.

The primary uncertainty in estimating emissions of CH_4 and N_2O from agricultural residue burning is the fraction of agricultural residue burned in the field. To avoid under- or overestimation and/or double counting, a mass balance must be performed to account for all the uses of the crop residues.

The methodology for estimating GHG emissions from burning of agricultural wastes is based, as in savannah burning, on 1) total carbon released, which is a function of the amount and efficiency of biomass burned and the carbon content of the biomass, and 2) the application of emission ratios of CH_4 and CO to total carbon released, and of N_2O and NO_x to total N released from biomass fires.

Equation 16
Total carbon released from burning agricultural residues

Total carbon released (tonnes of carbon) =

$\sum_{\text{all crop types}}$ annual production (tonnes of biomass per year),

x the ratio of residue to crop product (fraction),

x the average dry matter fraction of residue (tonnes of dry matter / tonnes of biomass),

x the fraction actually burned in the field,

x the fraction oxidised,

x the carbon fraction (tonnes of carbon / tonnes of dry matter)

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 4.82.

Equation 17
Calculation for trace gas emissions from burning

The calculation for trace gas emissions from burning is summarised as follows:

CH_4 Emissions = Carbon Released x (emission ratio) x 16/12

CO Emissions = Carbon Released x (emission ratio) x 28/12

N_2O Emissions = Carbon Released x (N/C ratio) x (emission ratio) x 44/28

NO_x Emissions = Carbon Released x (N/C ratio) x (emission ratio) x 46/14

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 4.83.

The default CH_4 and N_2O emission factors are presented in the Revised 1996 IPCC Guidelines, Reference Manual, table 4-16.

Default values, residue/crop product, dry matter fraction, carbon fraction (% dm), and nitrogen-carbon (N-C) ratio, are provided in the Revised 1996 IPCC Guidelines, Reference Manual, table 4-17.

The GPG 2000 estimates that 10 per cent of the total agricultural residue is burned in the field in developed countries and 25 per cent in developing countries. These figures may be too high. Good practice suggests that an estimate of 10 per cent may be more appropriate for developing countries.

4.10.3. ESTIMATING EMISSIONS USING COUNTRY-SPECIFIC VALUES

It is desirable to use country-specific values to reflect the national circumstances. The method is the same as for estimating emissions using default values.[18]

[18] For more information, see GPG 2000, p. 4.89.

5. SECTOR SPECIFIC ISSUES

5.1. AVOIDING DOUBLE COUNTING WITH OTHER SECTORS

Agricultural residue burning releases gases which are by-products of incomplete combustion: CH_4, CO, N_2O, and NOx, NO and NO_2. When dealing with this source category, special care should be given to avoid double counting as only the fraction of crop residues that are burned in the field to clear the land for the next crop should be included.

The percentage of the agricultural crop residues burnt on-site, which is the mass of fuel available for burning, should be estimated taking into account the fractions removed before burning due to other potential uses such as animal consumption, decay in the field and use in other sectors (e.g. biofuel, domestic livestock feed, building materials, etc.). This is important to eliminate the possibility of double counting. The fractions should be accounted for under other categories of the inventory such as: N_2O from agricultural soils (when applied to soils as fertilizers or organic amendments); energy (when burned as fuel); manure management and enteric fermentation (when used to feed animals).

Potential double counting of emissions associated with the application of managed manure should be avoided, as well as manure associated with pasture and grazing operations, which should be calculated and reported under N_2O emissions from managed soils.

Nitrous oxide from agricultural soils

It is necessary to account for the annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (Note: If including sewage sludge, cross-check with agriculture sector to ensure there is no double counting of N_2O emissions from the N in sewage sludge).

Enteric fermentation

The migration of livestock within or between countries may lead to double counting or undercounting of some animals such that seasonal changes in populations may not be adequately reflected in annual census data. The livestock population data should be examined in cooperation with the national statistical agencies with these factors in mind.

5.2. ACCOUNTING FOR CARBON DIOXIDE AND NON-CARBON DIOXIDE EMISSIONS FROM BIOMASS USE

The percentage of the agricultural crop residues burnt on-site, which is the mass of fuel available for burning, should be estimated taking into account the fractions removed before burning due to animal consumption, decay in the field and use in other sectors (e.g. biofuel, domestic livestock feed, building materials, etc.). This is important to eliminate the possibility of double counting. The fractions should be accounted for under other categories of the inventory such as: N_2O from agricultural soils (when applied to soils as fertilizers or organic amendments); energy (when burned as fuel); manure management and enteric fermentation (when used to feed animals).

5.3. QUALITY ASSURANCE AND QUALITY CONTROL

In the agriculture sector, transparency can be improved by the provision of clear documentation and explanations of work undertaken in the following specific areas in the various agriculture sector categories.

N_2O from agricultural soils

The Parties should compare country-specific data on synthetic fertilizer consumption with fertilizer usage data from the International Fertilizer Association (IFA) and synthetic fertilizer consumption estimates from the FAO. The Parties should ensure that N excretion data are consistent with those used for the manure management systems source category.

FAO crop production statistics, national crop production statistics and country-specific values for various parameters must be compared to IPCC defaults. The Parties should ensure that the quality assurance and quality control described in section 4.1 for livestock population characterization has been implemented and that a consistent livestock population characterization is used across sources.

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.

CH_4 from enteric fermentation

When using the tier 2 method, Parties should cross-check country-specific factors against the IPCC defaults.