Regional workshop for the "Capacity Development for sustainable national Greenhouse Gas Inventories – AFOLU sector" (CD-REDD II) Programme

Methods for estimating non-CO_2 and lime and urea emissions

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National Greenhouse Gas Inventories

Guidelines used by reporting Parties

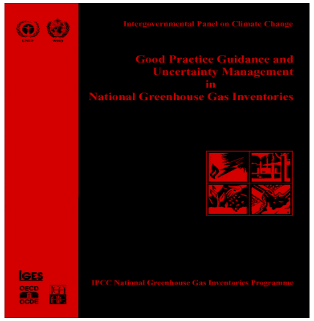
- Revised 1996 IPCC guidelines for national greenhouse gas inventories;

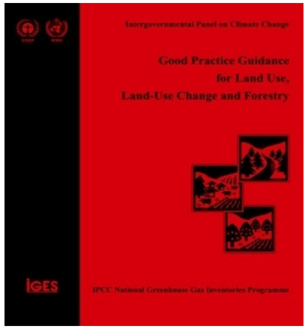
-IPCC Good practice guidance and uncertainty management in national greenhouse gas inventories (2000);

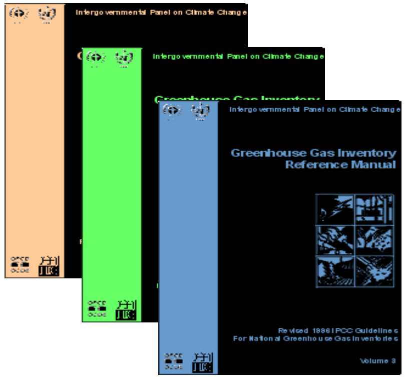
- IPCC Good practice guidance for land use, land use change and forestry (2003);

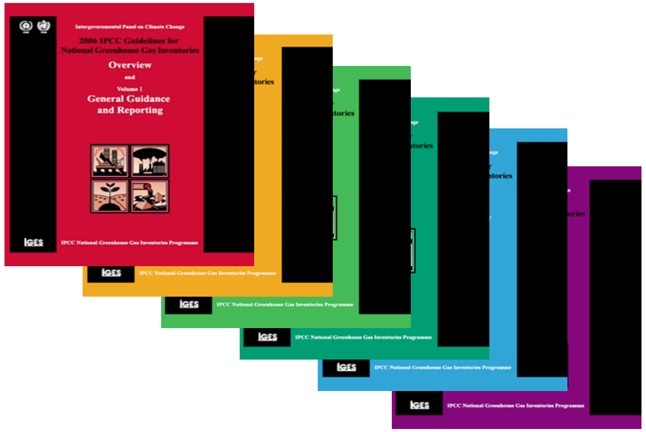
-2006 IPCC Guidelines for national greenhouse gas inventories (2006)

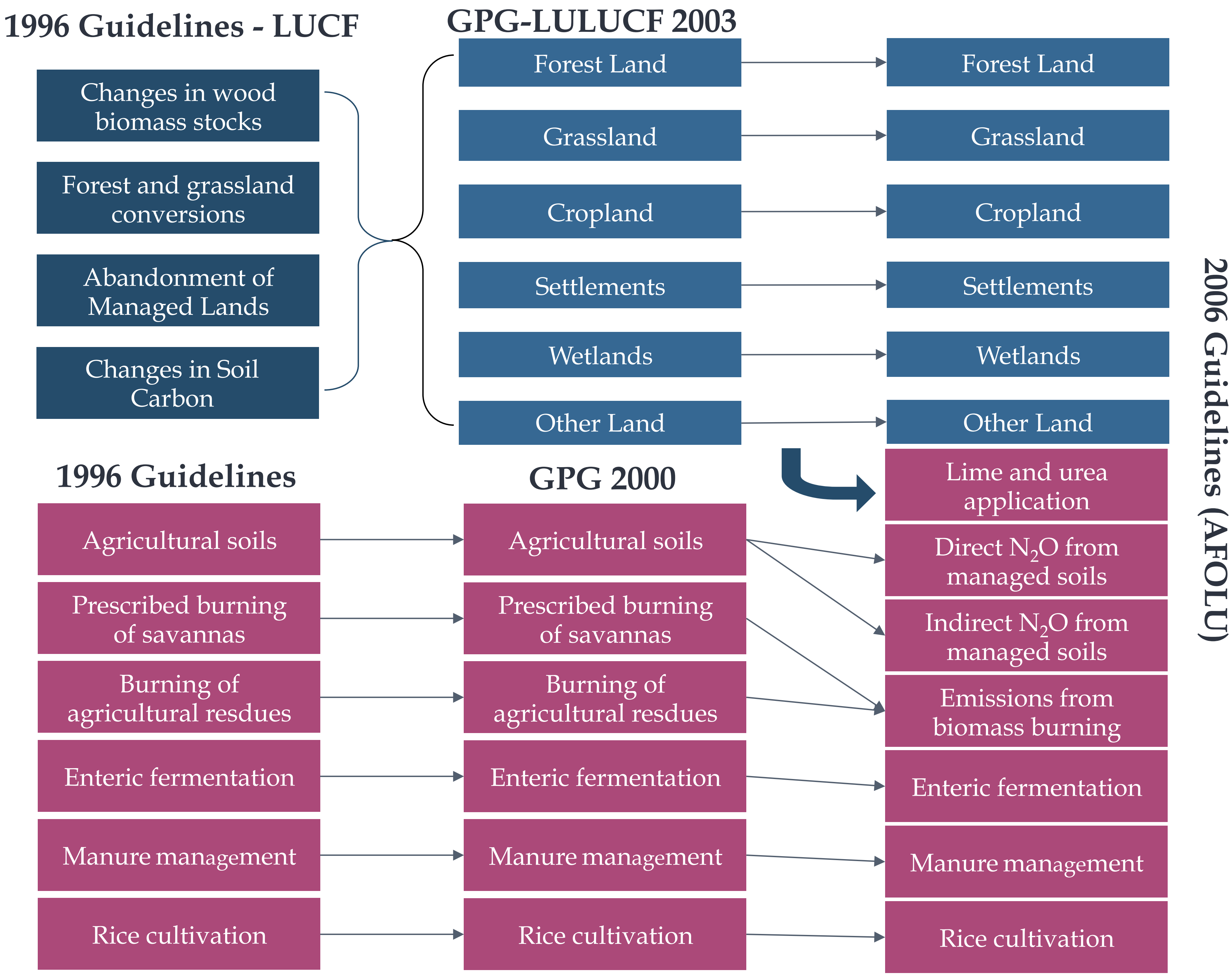
-Reporting for Kyoto Protocol (Art. 3.3 and 3.4): GPG LULUCF, chapter 4










1996 Guidelines - LUCF
Changes in wood biomass stocks
Forest and grassland conversions
Abandonment of Managed Lands
Changes in Soil Carbon
GPG-LULUCF 2003
Forest Land
Grassland
Cropland
Settlements
Wetlands
Other Land
Forest Land
Grassland
Cropland
Settlements
Wetlands
Other Land
2006 Guidelines (AFOLU)
1996 Guidelines
Agricultural soils
Prescribed burning of savannas
Burning of agricultural resdues
Enteric fermentation
Manure management
Rice cultivation
GPG 2000
Agricultural soils
Prescribed burning of savannas
Burning of agricultural resdues
Enteric fermentation
Manure management
Rice cultivation
Lime and urea application
Direct N_2O from managed soils
Indirect N_2O from managed soils
Emissions from biomass burning
Enteric fermentation
Manure management
Rice cultivation

Structure of AFOLU sector (vol. 4)

3A Livestock

- 3A1 Livestock
- 3A2 Manure Management

Chapt. 10

3B Land

- 3B1 Forest Land
- 3B2 Cropland
- 3B3 Grassland
- 3B4 Wetlands
- 3B5 Settlements
- 3B6 Other land

3C Aggregate sources and non CO_2 emissions sources on land

- 3C1 GHG emissions from biomass burning — Chapt. 4, 5, 6
- 3C2 Liming
- 3C3 Urea application
- 3C4 Direct N_2O emissions from managed soils — Chapt. 11
- 3C5 Indirect N_2O emissions from managed soils
- 3C6 Indirect N_2O emissions from manure management — Chapt. 10
- 3C7 Rice cultivation — Chapt. 5
- 3C8 Other
- 3D1 Harvested Wood Products
- 3D2 Other

3A Emissions from Livestock and Manure management

Livestock production can result in methane (CH_4) emissions from enteric fermentation and both CH_4 and nitrous oxide (N_2O) emissions from livestock manure management systems.

The methods for estimating CH_4 and N_2O emissions from livestock require definitions of livestock subcategories, annual populations and, for higher Tier methods, feed intake and characterization.

Livestock population and feed characterization

- Good practice is to identify the appropriate method for estimating emissions for each source category, and then base the characterization on the most detailed requirements identified for each livestock species.
- The livestock characterization used by a country will probably undergo iterations as the needs of each source category are assessed during the emissions estimation process.
- The approach is divided into 3 steps.

Livestock population and feed characterization

1. Identify livestock species applicable to each emission source category:
   - the livestock species that contribute to more than one emission source category should first be listed (*these species are typically: cattle, buffalo, sheep, goats, swine, horses, camels, mules/asses, and poultry*).
2. Review the emission estimation method for each relevant source category:
   - For the source categories of enteric fermentation and manure management, identify the emission estimating method for each species for that source category.
   - Similarly, manure management CH_4 emissions from cattle, buffalo, swine, and poultry should be examined to determine whether the Tier 2 or Tier 3 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.
3. On the basis of the assessments for each species under each source category, identify the most detailed characterization required to support each emissions estimate for each species

Livestock population and feed characterization: Tier 1

The following relation estimates the **annual average of livestock population**

$$AAP = Days\_alive \cdot \frac{NAPA}{365}$$

where:
AAP = *annual average population*
NAPA = *number of animals produced annually*

Dairy Cows and Milk Production:

The dairy cow population is estimated separately from other cattle. Dairy cows are defined in this method as mature cows that are producing milk in commercial quantities for human consumption. This definition corresponds to the dairy cow population reported in the FAO Production Yearbook. Dairy buffalo may be categorized in a similar manner to dairy cows.

Data on the average milk production of dairy cows is also required. Country-specific data sources are preferred, but FAO data may also be used. If two or more dairy cow categories are defined, the average milk production per cow is required for each category.

Livestock population and feed characterization: Tier 2

Tier 2: Enhanced characterization for livestock populations

The Tier 2 characterization methodology seeks to define animals, animal productivity, diet quality and management circumstances to support a more accurate estimate of feed intake for use in estimating methane production from enteric fermentation.

The Tier 2 livestock characterization requires detailed information on:

- Definitions for livestock sub-categories;
- Livestock population by sub-category, with consideration for estimation of annual population as per Tier 1;
- Feed intake estimates for the typical animal in each sub-category.

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

Livestock population and feed characterization: Tier 2

For each of the representative animal categories defined, the following information is required:

- annual average population *(number of livestock or poultry as per calculations for Tier 1);*
- average daily feed intake (MJ) and methane conversion factor *(% of feed energy converted to methane).*

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

- weight (kg);
- average weight gain per day (kg);
- feeding situation: confined, grazing, pasture conditions;
- milk production per day (kg/day) and fat content (%);
- average amount of work performed per day (hours/day);
- percentage of females that give birth in a year;
- wool growth;
- number of offspring; and, feed digestibility (%).

Livestock population and feed characterization: Tier 2 – Gross Energy

$$GE = \left[\frac{NE_m + NE_a + NE_l + NE_{work} + NE_p}{REM} + \frac{NE_g + NE_{wool}}{REG} \right] / \left(DE\% / 100 \right)$$

$NE_m = Cf_i \cdot (Weight)^{0.75}$	Net energy required by the animal for maintenance
$NE_a = C_a \cdot NE_m$ *for cattle and buffal* $NE_a = C_a \cdot weight$ *for sheep*	Net energy for animal actvity
$NE_l = milk \cdot (1.47 + 0.40 \cdot Fat)$ *for beef cattle, dairy cattle and buffal* $NE_l = milk \cdot (EV_{milk})$ *for sheep*	Net energy for lactation
$NE_{work} = 0.10 \cdot NE_m \cdot hours\ of\ work\ per\ day$	Net energy for work
$NE_p = C_{pregnancy} \cdot NE_m$	Net energy required for pregnancy
$REM = \left[1.123 - (4.092 \cdot 10^{-3} \cdot DE\%) + [1.126 \cdot 10^{-5} (DE\%)^2] - \frac{25.4}{DE\%} \right]$	Ratio of net energy available in a diet for maintenance to digestible energy consumed
$NE_g = 22.02 \cdot \left(\frac{BW}{C \cdot MW} \right)^{0.75} \cdot WG^{1.097}$ *for cattle and buffal* $NE_g = \frac{WG_{lamb} [a + 0.5 \cdot (BW_i + BW_f)]}{365}$ *for sheep*	Net energy for growth
$NE_{wool} = \frac{EV_{wool} \cdot production_{wool}}{365}$ *for sheep*	Net energy for wool production
$REM = \left[1.164 - (5.160 \cdot 10^{-3} \cdot DE\%) + [1.308 \cdot 10^{-5} (DE\%)^2] - \frac{37.4}{DE\%} \right]$	Ratio of net energy available for growth in a diet to digestible energy consumed

Livestock population and feed characterization: Tier 2

The Tier 2 approach is a data intensive method.

It is important to be aware of national statistics limitations, both in consideration of the livestock categories and disaggregation level.

Need to identify data already existing and list any additional data need to be collected.

Time series consistency has to be ensure, especially in case of different Tier applied to different livestock categories or different disaggregation level.

Tier 2 method requires time and resources to be followed, in order to acquire and process the additional data. A cost-benefit analysis should be carry out before choice the Tier approach.

Methane emissions from enteric fermentation

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

The amount of methane that is released depends on the type of digestive tract, age, and weight of the animal, and the quality and quantity of the feed consumed.

Ruminant livestock (*e.g., cattle, sheep*) are major sources of methane with moderate amounts produced from nonruminant livestock (*e.g., pigs, horses*).

IPCC methodology provides for **three steps**, which can be applied to all methodological tiers and can be performed at varying levels of detail and complexity.

→***Step 1*:** Divide the livestock population into subgroups and characterize each subgroup.

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

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

Methane emissions from enteric fermentation: Tiers

Tier 1

- A simplified approach that relies on default emission factors either drawn from the literature or calculated using the more detailed Tier 2 methodology.
- The Tier 1 method is likely to be suitable for most animal species in countries where enteric fermentation is not a key source category, or where enhanced characterization data are not available.

Tier 2

- A more complex approach that requires detailed country-specific data on gross energy intake and methane conversion factors for specific livestock categories.
- Should be used if enteric fermentation is a key source category for an animal category that represents a large portion of the total emissions.

Tier 3

- Additional country-specific information for the estimation process.
- May employ the development of models, considering diet composition, seasonal variation in animal population or feed quality and availability.
- Many of estimates would be derived from direct experimental measurements.

Methane emissions from enteric fermentation: data requirements

→ **Livestock characterization as discussed earlier**

→ **Emission factors:**

- The Guidelines provide default emission factors for all different animal categories (Tier 1);
- For a tier 2/3 method, the Guidelines provide guidance on how to develop and use country specific emission factors

To estimate total emission, the selected emission factors are multiplied by the associated animal population and summed:

$$Emissions = EF_{(T)} \cdot \frac{N_{(T)}}{10^6\, kg / Gg}$$

where:

Emissions = *methane emissions from enteric fermentation, Gg CH_4 yr^{-1}*

$EF_{(T)}$ = *emission factor for the defined livestock population, kg head-1 yr^{-1}*

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

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

where:

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

E_i = *emission for the i^{th} livestock categories and subcategories*

Methane emissions from enteric fermentation: QA/QC

It is good practice to implement quality control checks as outlined in Volume 1, Chapter 6 (*Quality Assurance/Quality Control and Verification*). In addition:

→ Activity data check

- The inventory compiler should review livestock data collection methods, in particular checking that livestock subspecies data were collected and aggregated correctly.
- The data should be cross-checked with previous years to ensure the data are reasonable and consistent with the expected trend.
- Inventory compilers should document data collection methods, identify potential areas of bias, and evaluate the representativeness of the data.
- Population modeling can be used to support this approach.

→ Review of emission factors

- If using the Tier 2/Tier 3 method, the inventory compiler should cross-check country-specific factors against the IPCC defaults. Significant differences between country-specific factors and default factors should be explained and documented.

Methane emissions from manure management

The main factors affecting CH_4 emissions are:

– amount of manure produced

– portion of the manure that decomposes anaerobically.

When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it decomposes anaerobically and can produce a significant quantity of CH_4.

– The temperature and the retention time of the storage unit greatly affect the amount of methane produced.

When manure is handled as a solid (e.g., in stacks or piles) or when it is deposited on pastures and rangelands, it tends to decompose under more aerobic conditions and less CH_4 is produced.

Methane emissions from manure management

Methodology

- ***Step 1***: Collect population data from the Livestock Population Characterization.
- ***Step 2:*** Use default values or develop country-specific emission factors for each livestock subcategory in terms of kilograms of methane per animal per year.
- ***Step 3***: Multiply the livestock subcategory emission factors by the subcategory populations to estimate subcategory emissions, and sum across the subcategories to estimate total emissions by primary livestock species.
- ***Step 4***: Sum emissions from all defined livestock species to determine national emissions.

$$CH_{4Manure} = \sum_{(T)} \frac{EF_{(T)} \cdot N_{(T)}}{10^6 kg / Gg}$$

where:

$CH_{4Manure}$ = *CH_4 emissions from manure management, for a defined population, Gg CH_4 yr^{-1}*
$EF_{(T)}$ = *emission factor for the defined livestock population, kg head-1 yr^{-1}*
$N_{(T)}$ = *the number of head of livestock species / category T in the country*
T = *Species/category of livestock*

Methane emissions from manure management: Tier 1

The method chosen will depend on data availability and national circumstances.

The Tier 1 method should only be used if it is determined that the source is not a key category or subcategory and there is no possibility to use the Tier 2 method.

Countries for which livestock emissions are particularly important may wish to go beyond the Tier 2 method and develop models for country specific methodologies or use measurement–based approaches to quantify emission factors (Tier 3).

Tier 1

– only requires livestock population data by animal species/category and climate region or temperature, in combination with IPCC default emission factors, to estimate emissions. Tables 10A-4 through 10A-9 (IPCC GL 2006 - Annex 10A.2) present the underlying assumptions used for each region; countries using a Tier 1 method should review the regional variables to identify the region that most closely matches their animal operations, and use the default emission factors for that region.

- Default emission factors by average annual temperature are presented in Table 10.14, Table 10.15, and Table 10.16 for each of the recommended population subcategories. These emission factors represent the range in manure volatile solids content and in manure management practices used in each region, as well as the difference in emissions due to temperature.

Methane emissions from manure management: Tier2

Tier 2

– Detailed information on animal characteristics and manure management practices are required; the information is used to develop emission factors specific to the conditions of the country.

- The Tier 2 method relies on two primary types of inputs that affect the calculation of methane emission factors from manure:

- ***Manure Characteristics:*** Includes the amount of volatile solids (VS) produced in the manure and the maximum amount of methane able to be produced from that manure (Bo). Production of manure VS can be estimated based on feed intake and digestibility, which are the variables also used to develop the Tier 2 enteric fermentation emission factors.

- ***Manure Management***: Includes the types of systems used to manage manure and a system-specific methane conversion factor (MCF) that reflects the portion of Bo that is achieved. Regional assessments of manure management systems are used to estimate the portion of the manure that is handled with each manure management technique.

Methane emissions from manure management: Tier 2

annual CH_4 emission factor

$$EF_{(T)} = VS_{(T)} \cdot 365 \cdot \left[B_{0(T)} \cdot 0.67 kg \cdot m^{-3} \cdot \sum_{S,k} \frac{MCF_{S,k}}{100} \cdot MS_{(T,S,k)} \right]$$

where:

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

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

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

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

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

$MS_{(T,S,k)}$ = *fraction of livestock category T's manure handled using manure management system S in climate region k, dimensionless*

Even when the level of detail presented in the Tier 2 method is not possible in some countries, country-specific data elements such as **animal mass**, **VS excretion**, and others can be used to improve emission estimates. If country-specific data are available for only a portion of these variables, countries are encouraged to calculate country-specific emission factors, using the data in Tables 10A-4 through 10A-9 to fill gaps.

Methane emissions from manure management: Tier 2

Volatile solids (VS) excretion rate

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

where:

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

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

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

UE • GE = *urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). Use country-specific values where available.*

ASH = *the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle). Use country-specific values where available.*

The best way to obtain average daily VS excretion rates is to use data from nationally published sources. If average daily VS excretion rates are not available, country-specific **VS excretion rates** can be estimated from feed intake levels. Countries should estimate **gross energy (GE)** intake (Equation 10.16) and its **fractional digestibility, DE**, in the process of estimating enteric methane emissions.

Methane emissions from manure management: Tier 2

B_O values

The maximum methane producing capacity of the manure (Bo) varies by species and diet. The preferred method to obtain Bo measurement values is to use data from country-specific published sources, measured with a standardized method. If country-specific Bo measurement values are not available, default values are provided in Annex 10A.2 (Tables 10A-4 through 10A-9).

MCFs

Default methane conversion factors (MCFs) are provided in Guidelines for different manure management systems and by annual average temperatures. MCFs are determined for a specific manure management system and represent the degree to which Bo is achieved. The amount of methane generated by a specific manure management system is affected by the extent of anaerobic conditions present, the temperature of the system, and the retention time of organic material in the system.

Methane emissions from manure management: QA/QC

It is good practice to implement quality control checks as outlined in Volume 1, Chapter 6 (*Quality Assurance/Quality Control and Verification*). In addition:

→ Activity data check

- The inventory compiler should review livestock data collection methods, in particular checking that livestock subspecies data were collected and aggregated correctly.
- Manure management system allocation should be reviewed on a regular basis to determine if changes in the livestock industry are being captured.
- Conversion from one type of management system to another, and technical modifications to system configuration and performance, should be captured in the system modeling for the affected livestock.
- National agricultural policy and regulations may have an effect on parameters that are used to calculate manure emissions, and should be reviewed regularly to determine what impact they may have.

Methane emissions from manure management: QA/QC

It is good practice to implement quality control checks as outlined in Volume 1, Chapter 6 (*Quality Assurance/Quality Control and Verification*). In addition:

→ Review of emission factors

- If using the Tier 1 method, should evaluate how well the default parameters and the manure management practices represent the animal population and manure characteristics of the country. If there is not a good match, substitution of more appropriate country-specific parameters can be used to develop an improved emission factor.
- If using the Tier 2 method, the inventory agency should cross-check the country-specific parameters against the IPCC defaults. Significant differences between country-specific parameters and default parameters should be explained and documented.

→ External review

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

Nitrous oxide emissions from manure management

The section describes how to estimate the N_2O produced, directly and indirectly, during the storage and treatment of manure before it is applied to land or otherwise used for feed, fuel, or construction purposes.

→ Direct N_2O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, and on the duration of the storage and type of treatment.

→ Indirect emissions result from volatile nitrogen losses that occur primarily in the forms of ammonia and NO_x. The fraction of excreted organic nitrogen that is mineralized to ammonia nitrogen during manure collection and storage depends primarily on time, and to a lesser degree temperature.

→ Due to significant direct and indirect losses of manure nitrogen in management systems it is important to estimate the remaining amount of animal manure nitrogen available for application to soils or for use in feed, fuel, or construction purposes. This value is used to estimate N_2O emissions from managed soils.

Nitrous oxide emissions from manure management

Direct N_2O Emissions from Manure Management

Tier 1: the method requires multiplying the total amount of N excretion (from all livestock species/categories) in each type of manure management system by an emission factor for that type of manure management system. Emissions are then summed over all manure management systems. The Tier 1 method is applied using IPCC default N_2O emission factors, default nitrogen excretion data, and default manure management system data

Tier 2: follows the same calculation equation as Tier 1 but would include the use of country specific data for some or all of these variables

Tier 3: utilizes alternative estimation procedures based on a country-specific methodology.

Nitrous oxide emissions from manure management

Direct N_2O Emissions from Manure Management

Step 1: Collect population data from the Livestock Population Characterization;

Step 2: Use default values or develop the annual average nitrogen excretion rate per head ($N_{ex(T)}$) for each defined livestock species/category T;

Step 3: Use default values or determine the fraction of total annual nitrogen excretion for each livestock species/category T that is managed in each manure management system S ($MS_{(T,S)}$);

Step 4: Use default values or develop N_2O emission factors for each manure management system S ($EF_{3(S)}$);

Step 5: For each manure management system type S, multiply its emission factor ($EF_{3(S)}$) by the total amount of nitrogen managed (from all livestock species/categories) in that system, to estimate N_2O emissions from that manure management system. Then sum over all manure management systems.

Nitrous oxide emissions from manure management

Direct N_2O Emissions from Manure Management

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T \left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}\right)\right] EF_{3(S)}\right] \cdot \frac{44}{28}$$

where:

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

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

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

$EF_{3(S)}$ =*Emission factor for direct N2O emissions from manure management system S in the country, kg N_2O-N/kg N in manure management system S*

S = *Manure management system*

T = *Species/category of livestock*

44/28 = *Conversion of (N_2O-N)(mm) emissions to N_2O(mm) emissions*

Nitrous oxide emissions from manure management

Indirect N_2O Emissions from Manure Management

Tier 1: is based on multiplication of the amount of nitrogen excreted (from all livestock categories) and managed in each manure management system by a fraction of volatilized nitrogen. N losses are then summed over all manure management systems.

$$N_{volatization-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}\right) \cdot \left(\frac{Frac_{GasMS}}{100}\right)_{(T,S)}\right]\right]$$

where:

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

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

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

$Frac_{GasMS}$ = *percent of managed manure nitrogen for livestock category T that volatilizes as NH_3 and NO_x in the manure management system S, %*

Nitrous oxide emissions from manure management

Indirect N_2O Emissions from Manure Management

Tier 1

The indirect N_2O emissions from volatilization of N in forms of NH_3 and NO_x ($N_2O_{G\,(mm)}$) are estimated as:

$$N_2O_{G(mm)} = N_{volatization-MMS} \cdot EF_4 \cdot \frac{44}{28}$$

where:

$N_2O_{G(mm)}$ = Indirect N_2O emissions due to volatilization of N from manure management in the country, kg N_2O yr^{-1}

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

Nitrous oxide emissions from manure management

Tier 2

As for direct N_2O emission from manure management, a Tier 2 method would follow the same calculation equation as Tier 1 but include the use of country-specific data for some or all of these variables.

A Tier 2 method would require more detailed characterization of the flow of nitrogen throughout the animal housing and manure management systems used in the country.

There are extremely limited measurement data on leaching and runoff losses from various manure management systems. The greatest N losses due to run-off and leaching typically occur where animals are on a drylot. ***Estimation of N losses from leaching and run off from manure management should be considered part of a Tier 2 or Tier 3 method,*** as country-specific information on the fraction of nitrogen loss due to leaching and run-off from manure management systems are needed.

Nitrous oxide emissions from manure management

Indirect N_2O Emissions from Manure Management: **Tier 2**

$$N_{leaching-MMS} = \sum_s \left[\sum_T \left[\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)} \right) \cdot \left(\frac{Frac_{leachMS}}{100} \right)_{(T,S)} \right] \right]$$

where:

$N_{leaching\text{-}MMS}$ = *amount of manure nitrogen that leached from manure management systems, kg N yr-1*

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

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

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

$F_{racleachMS}$ = *percent of managed manure nitrogen 1 losses for livestock category T due to runoff and leaching during solid and liquid storage of manure*

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

where:

$N_2O_{L(mm)}$ = *indirect N_2O emissions due to leaching and run-off from manure management in the country, kg N_2O yr^{-1}*

EF_5 = *emission factor for N_2O emissions from nitrogen leaching and run-off, kg N_2O-N/kg N leached and run-off*

Nitrous oxide from manure management: QA/QC

→ Activity data check

- The inventory compiler should review livestock data collection methods, in particular checking that livestock subspecies data were collected and aggregated correctly.
- Manure management system allocation should be reviewed on a regular basis to determine if changes in the livestock industry are being captured.
- National agricultural policy and regulations may have an effect on parameters that are used to calculate manure emissions, and should be reviewed regularly to determine what impact they may have.
- Country-specific data for $Nex_{(T)}$ and $MS_{(T,S)}$, if any, should be compared to the IPCC default values.

→ Review of emission factors

- A comparison of the implied N_2O emission factors and nitrogen excretion rates with alternative national data sources and with data from other countries with similar livestock practices should be carry out.
- Country-specific emission factors should be compared to the default factors and note differences.

Methane emissions from rice cultivation

Anaerobic decomposition of organic material in flooded rice fields produces CH_4, which escapes to the atmosphere primarily by transport through the rice plants.

The annual amount of CH_4 emitted from a given area of rice is a function of the number and duration of crops grown, water regimes before and during cultivation period, and organic and inorganic soil amendments. Soil type and temperature also affect CH_4 emissions.

The 2006 IPCC GLs incorporate the following changes:

– Revision of emission and scaling factors derived from updated analysis of available data;

– Use of daily, instead of seasonal, emission factors to allow more flexibility in separating cropping seasons and fallow periods;

– New scaling factors for water regime before the cultivation period and timing of straw incorporation; and

– Inclusion of Tier 3 approach.

Methane emissions from rice cultivation

CH_4 emissions are estimated by multiplying daily emission factors by cultivation period of rice and annual harvested areas:

$$CH_{4\,Rice} = \sum_{i,j,k} \left(EF_{i,j,k} \cdot t_{i,j,k} \cdot A_{i,j,k} \cdot 10^{-6} \right)$$

where:

$CH_{4\,Rice}$ = *annual methane emissions from rice cultivation, Gg* CH_4 yr^{-1}

EF_{ijk} = *a daily emission factor for i, j, and k conditions, in kg CH4* ha^{-1} day^{-1}

t_{ijk} = *cultivation period of rice for i, j, and k conditions, in day*

A_{ijk} = *annual harvested area of rice for i, j, and k conditions, in ha* yr^{-1}

i,j, k = *represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions.*

The different conditions that should be considered include rice ecosystem type, flooding pattern before and during cultivation period, type and amount of organic amendments.

Methane emissions from rice cultivation: Tiers

Tier 1 applies to countries in which either CH_4 emissions from rice cultivation are not a key category or country- specific emission factors do not exist.

- The disaggregation of the annual harvest area of rice needs to be done for at least three baseline water regimes including irrigated, rainfed, and upland.
- Incorporate as many of the conditions (i, j, k, etc.) that influence CH_4 emissions as possible. The calculations are carried out for each water regime and organic amendment separately.

Tier 2 applies the same methodological approach as Tier 1, but country-specific emission factors and/or scaling factors should be used.

- These country-specific factors are needed to reflect the local impact of the conditions (i, j, k, etc.) that influence CH_4 emissions, preferably being developed through collection of field data.

Tier 3 includes models and monitoring networks tailored to address national circumstances of rice cultivation, repeated over time, driven by high-resolution activity data and disaggregated at sub-national level.

Methane emissions from rice cultivation: QA/QC

→ Measurements of standard methane emissions:

- The inventory QC procedures used at the rice field level will be determined largely by local scientists. There are, however, certain internationally determined procedures to obtain 'standard emission factors' that should be common to all monitoring programmes.

→ Compiling national emissions:

- Before accepting emissions data, an assessment of data quality and sampling procedures, include sample Recalculations should be carry out, as an assessment on reliability of agronomic and climate data, an identification of potential bias in the methodology.
- The inventory agency should ensure that emissions estimates undergo QC 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; and
  - Cross-referencing reported national totals with default values and data from other countries.

Nitrous oxide emissions from managed soils

Nitrous oxide is generated in managed soils through microbial processes (nitrification – aerobic, and denitrification – anaerobic). The amount of N_2O released (i.e. occurrence of reactions) depends on availability of inorganic N in the soil (i.e. through human additions or changes in practices that mineralize the soil organic N).

Methodology is therefore based on additions of net N to soils by humans from: synthetic and organic fertilizers, animal waste or deposited manure, crop residues, sewage sludge or other organic N additions

N_2O emissions can occur in the form of direct emissions (directly from the soil to which N was added/released) or indirect emissions (volatilization and deposition, or leaching and runoff).

Direct and indirect N_2O emissions are estimated separately, but same set of activity data is used.

General approach: Compile national-level statistics for N management

Since AD not broken down by land use type, Tier 1 based on national aggregate data

Nitrous oxide emissions from managed soils

Direct N_2O emissions

Main N sources

- Synthetic N fertilizers (F_{SN})
- organic N applied as fertilizer (animal manure, compost, sewage sludge, etc) (F_{ON})
- urine & dung N deposited on pastures by grazing animals (F_{PRP})
- N in crop residues (F_{CR})
- N mineralization from loss of soil organic matter due to changes in land use or management practices (F_{SOM})
- drainage/management of organic soils (F_{OS})

3 methodological approaches

- For each N source: country-specific activity data available, is this N source significant?
- **Tier 1**: default EF and FAO activity data (for fertilizer) or country activity data
- **Tier 2**: need country-specific emission factors
- **Tier 3**: Modelling or measurement approaches

Nitrous oxide emissions from managed soils

Direct N_2O emissions:

Tier 1

Annual direct N_2O emissions is sum of annual direct N emissions from:

- N input to managed soils (default EF: for amount synthetic and organic N input to soil including crop residues, mineralization)
- managed organic soils (default EF: amount of N_2O from an area of drained/managed organic soil)
- urine and dung inputs to grazed soils (default EF: amount of N_2O from urine and dung deposited by grazing animals)
- Each requires specific emission factors and associated data

$$N_2O_{Direct} - N = N_2O - N_{N\ inputs} + N_2O - N_{OS} + N_2O - N_{PRP}$$

where:

N_2O_{Direct} -N = *annual direct N_2O-N emissions produced from managed soils, kg N_2O-N yr^{-1}*
N_2O-$N_{N\ inputs}$ = *annual direct N_2O-N emissions from N inputs to managed soils, kg N_2O-N yr^{-1}*
N_2O-N_{OS} = *annual direct N_2O-N emissions from managed organic soils, kg N_2O-N yr^{-1}*
N_2O-N_{PRP} = *annual direct N_2O-N emissions from urine and dung inputs to grazed soils, kg N_2O-N yr^{-1}*

Nitrous oxide emissions from managed soils

Direct N_2O emissions

Tier 2

– Expansion of tier 1 equation, allowing further disaggregation (e.g. different conditions)

– Allows to accommodate any combination of N source, crop type, management, land use, climate, soil or other condition-specific emission factor

<u>Examples of data requirements</u>

→ Applied synthetic fertilizer:
Annual fertilizer consumption data may be collected by official country statistics, fertilizer sales, import, production (Default: FAO, International Fertilizer Industry Association (IFIA))

→ Applied organic N fertilizer (other than from grazing animals)
Calculated from annual amount of animal manure N applied to soils (requires fractions used for feed, fuel or construction), total sewage N, total compost N and other organic amendments

→ Urine and dung from grazing animals
Data from livestock (N_2O manure management) can be used.

Nitrous oxide emissions from managed soils

Indirect N_2O emissions

Emissions of N_2O take place through two indirect pathways:

1. Volatilization of N as NH_3 and oxides of N (NO_x), and the deposition of these gases and their products NH_4^+ and NO_3^- onto soils and the surface of lakes and other waters. The sources of N as NH_3 and NO_x are not confined to agricultural fertilisers and manures, but also include fossil fuel combustion, biomass burning, and processes in the chemical industry.
2. Leaching and run-off from land of N from synthetic and organic fertilizers, manure, crop residues etc.

It is possible to estimate aggregate total indirect N_2O emissions from agricultural N additions for the entire country (i.e. not necessarily by land-use categories)

Depending on availability of country-specific data: Tier 1 or Tier 2 or combination (Tier 3: modelling or measurement approaches)

Nitrous oxide emissions from managed soils

Indirect N_2O emissions

Data and emission factor requirements (for **Tier 1**)

- activity data: requirements are the same than for direct N_2O emissions
- emission factors for volatilized and re-deposited N (defaults available)
- emission factors for N lost through leaching/runoff (defaults available)
- Values for fractions (partitioning fractions) of N that is lost through volatilization or leaching/runoff (defaults available)

Tier 2

If more detailed emission, volatilization or leaching factors are available to a country, further disaggregation of the terms included in the computation relation to N_2O estimates can also be undertaken. (i.e. if specific volatilization factors are available for the application of synthetic fertilizers (F_{SN}) under different conditions, different estimates of amount of N_2O produced from atmospheric deposition of volatized N may be computed, depending of the fertilization application system).

Nitrous oxide emissions from managed soils

Indirect N_2O emissions: Tier 1

Volatilisation $N_2O_{(ATD)}$

$$N_2O_{(ATD)} - N = \left[F_{SN} \cdot Frac_{GASF} + \left(F_{ON} + F_{PRP}\right) \cdot Frac_{GASF}\right] \cdot EF_4$$

where:

$N_2O_{(ATD)}$-N = annual amount of N_2O-N produced from atmospheric deposition of N volatilised from managed soils, kg N_2O-N yr^{-1}

F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N yr^{-1}

$Frac_{GASF}$ = fraction of synthetic fertiliser N that volatilises as NH_3 and NO_x, kg N volatilised (kg of N applied)$^{-1}$

F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils, kg N yr^{-1}

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr^{-1}

$Frac_{GASM}$ = fraction of applied organic N fertiliser materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilises as NH_3 and NO_x, kg N volatilised (kg of N applied or deposited)$^{-1}$

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, [kg N- N_2O (kg NH_3-N + NO_x-N volatilised)$^{-1}$]

Nitrous oxide emissions from managed soils

Indirect N_2O emissions: **Tier 1**

Leaching/Runoff $N_2O_{(L)}$

$$N_2O_{(L)} - N = \left(F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}\right) \cdot Frac_{LEACH-(H)} \cdot EF_5$$

where:

$N_2O_{(L)}$-N = annual amount of N_2O-N produced from from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kg N_2O-N yr^{-1}

F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N yr^{-1}

$Frac_{GASF}$ = fraction of synthetic fertiliser N that volatilises as NH_3 and NO_x, kg N volatilised (kg of N applied)$^{-1}$

F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils in regions where leaching/runoff occurs, kg N yr^{-1}

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock in regions where leaching/runoff occurs, kg N yr^{-1}

F_{CR} = amount of N in crop residues (above and below ground), including N-fixing crops, and from forage/pasture renewal, returned to soils annually, kg N yr_{-1}

FSOM = annual amount of N mineralised in mineral soils associated 1 with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr-1

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralised in managed soils that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$

EF_5 = emission factor for N_2O emissions from N leaching and runoff, kg N_2O-N (kg N leached and runoff)$^{-1}$

Nitrous oxide emissions from managed soils

Indirect N_2O emissions: Tier 1

Default emission, volatilization and leaching factors can be found in the Table 11.3.

TABLE 11.3
DEFAULT EMISSION, VOLATILISATION AND LEACHING FACTORS FOR INDIRECT SOIL N_2O EMISSIONS

Factor	Default Value	Uncertainty Range
EF_4 [N volatilisation and re-deposition], kg N_2O-N (kg NH_3-N + NO_X–N volatilised)$^{-1}$ [22]	0.010	0.002-0.05
EF_5 [leaching/runoff], kg N_2O-N (kg N leaching/runoff)$^{-1}$ [23]	0.0075	0.0005-0.025
$Frac_{GASF}$ [Volatilisation from synthetic fertiliser], (kg NH_3-N + NO_x-N) (kg N applied)$^{-1}$	0.10	0.03-0.3
$Frac_{GASM}$ [Volatilisation from all organic N fertilisers applied , and dung and urine deposited by grazing animals], (kg NH_3-N + NO_x-N) (kg N applied or deposited)$^{-1}$	0.20	0.05-0.5
$Frac_{LEACH-(H)}$ [N losses by leaching/runoff for regions where Σ(rain in rainy season) - Σ (PE in same period) > soil water holding capacity, OR where irrigation (except drip irrigation) is employed], kg N (kg N additions or deposition by grazing animals)$^{-1}$	0.30	0.1 – 0.8

Indirect N_2O emissions: Tier 2

If more detailed emission, volatilisation or leaching factors are available to a country than are presented in Table 11.3, further disaggregation of the terms in the equations can also be undertaken. For example, if specific volatilisation factors are available for the application of synthetic fertilisers (F_{SN}) under different conditions *i*.

Nitrous oxide emissions from managed soils: QA/QC

→ Review of emission factors

— country-specific values to be compared against IPCC defaults and those by other countries with comparable circumstances.

→ activity data check:

— compare national statistics (e.g. fertilizer consumption, crop production) with international data (FAO, IFIA);

— ensure consistency of N excretion data with those used for manure management;

— ensure that QA/QC has been completed for livestock characterization, because same data are used in other inventory categories.

CO_2 emissions from liming

Liming is used to reduce soil acidity and improve plant growth in managed systems, particularly agricultural lands and managed forests.

It is good practice for countries to use higher tiers if CO_2 emissions from liming are a key source category.

Tier 1

$$CO_2\text{-}C\ Emission = (M_{Limestone} \cdot EF_{Limestone}) + (M_{Dolomite} \cdot EF_{Dolomite})$$

where:

CO_2-C Emission	= *annual C emissions from lime application, tonnes C yr^{-1}*
M	= *annual amount of calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$), tonnes yr^{-1}*
EF	= *emission factor, tonne of C per tonne of limestone or dolomite*

The overall emission factor (EF) for limestone is equal to 0.12 and 0.13 for dolomite.

Tier 2 inventories also use the same Tier 1 equation, but incorporate country-specific data to derive emission factors (EF).

Overall, the CO_2 emissions from liming are expected to be less than using the Tier 1 approach, which assumes that all C in applied lime is emitted as CO_2 in the year of application.

CO_2 emissions from urea fertilization

Adding urea to soils during fertilisation leads to a loss of CO_2 that was fixed in the industrial production process. This source category is included because the CO_2 removal from the atmosphere during urea manufacturing is estimated in the Industrial Processes and Product Use Sector. It is good practice for countries to use higher tiers if CO_2 emissions from urea are a key source category.

Tier 1

$$CO_2\text{-}C\ Emission = M \cdot EF$$

where:

CO_2-C Emission = *annual C emissions from urea application, tonnes C yr^{-1}*
M = *annual amount of urea fertilisation, tonnes yr^{-1}*
EF = *emission factor, tonne of C (tonne of urea)$^{-1}$*

The overall emission factor (EF) for urea is equal to 0.20, which is equivalent to the carbon content of urea on an atomic weight basis (20% for $CO(NH_2)_2$).

Tier 2 inventories also use the same Tier 1 equation, but incorporate country-specific data to derive emission factors (EF).

Emissions from biomass burning

Emissions from fire include not only CO_2, but also other GHG, or precursors of greenhouse gases, that originate from incomplete combustion of the fuel. These include carbon monoxide (CO), methane (CH_4), non-methane volatile organic carbon (NMVOC) and nitrogen (e.g. N_2O, NO_x) species,

In the 2006 Guidelines, fire is treated as a disturbance that affects not only the biomass (in particular, above-ground), but also the dead organic matter (litter and dead wood). For cropland and grassland having little woody vegetation, reference is usually made to biomass burning, since biomass is the main pool affected by the fire.

Main difference compared to the 1996 Guidelines and 2003 GPG-LULUCF

In the 1996 Guidelines, field burning of agricultural residues was an own source category under the agriculture sector (4.F) (CH_4 and N_2O emissions). In the 2006 Guidelines, these emissions are included as non-CO_2 from crop residue burning under the land-use categories, i.e. *cropland remaining cropland*. In addition, they are included as non-CO_2 from biomass burning under *Lands converted to forest land* or to *grassland*.

In the GPG-LULUCF, emissions (CO_2 and non-CO_2) from fires were addressed, particularly for *forest land* category. Concerning *cropland* and *grassland*, only non-CO_2 emissions were considered, with the assumption that the CO_2 emissions would be counterbalanced by CO_2 removals from the subsequent re-growth of the vegetation within one year.

Emissions from biomass burning

Coverage of reporting: Emissions need to be reported for all fires on managed lands. In case of land-use change, any GHG emission from fire should be reported under the new land-use category. Emissions from wildfires that occur on unmanaged lands do not need to be reported, unless those lands are followed by a land-use change (i.e., become managed land).

Equivalence (synchrony) of CO_2 emissions and removals: CO_2 net emissions should be reported where the CO_2 emissions and removals for the biomass pool are not equivalent in the inventory year. For *grassland* biomass burning and burning of agriculture residues, the assumption of equivalence is generally reasonable. In *Forest land remaining Forest land*, emissions of CO_2 from biomass burning also need to be accounted for because they are generally not synchronous with rates of CO_2 uptake. This is especially important after stand replacing wildfire, and during cycles of shifting cultivation in tropical regions.

Fuels available for combustion: Factors that reduce the amount of fuels available for combustion (e.g., from grazing, decay, removal of biofuels, livestock feed, etc.) should be accounted for. A mass balance approach should be adopted to account for residues, to avoid underestimation or double counting.

Annual reporting: countries should estimate and report greenhouse gas emissions from fire on an annual basis.

Emissions from biomass burning

Methods and related elements (e.g. decision trees, basic equation, combustion and emission factors, etc.) are generic across land-use categories (chapter 2.4)

Tier 1:

$$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-6}$$

where:

L_{fire} = *amount of greenhouse gas emissions from fire, tonnes of each GHG e.g.,* CH_4, N_2O, *etc.*

A = *area burned, ha*

M_B = *mass of fuel available for combustion, tonnes* ha^{-1}. *This includes biomass, ground litter and deadwood. When Tier 1 methods are used then litter and dead wood pools are assumed zero, except where there is a land-use change.*

C_f = *combustion factor, dimensionless (default values in Table 2.6)*

G_{ef} = *emission factor, g* kg^{-1} *dry matter burnt (default values in Table 2.5)*

Note: Where data for MB and Cf are not available, a default value for the amount of fuel actually burnt (the product of M_B *and* C_f *) can be used (Table 2.4) under Tier 1 methodology*

Tier 2: use of country-derived emission and combustion factors and fuel density (major crop types by climate zone)

Tier 3: more comprehensive, include consideration of dynamics of fuels (biomass and dead organic matter)

Emissions from biomass burning

Default values fuel consumptions for different vegetation types can be found in the table 2.4:

TABLE 2.4
FUEL (DEAD ORGANIC MATTER PLUS LIVE BIOMASS) BIOMASS CONSUMPTION VALUES (TONNES DRY MATTER HA^{-1}) FOR FIRES IN A RANGE OF VEGETATION TYPES

(To be used in Equation 2.27 , to estimate the product of quantities ' $M_B \bullet C_f$ ' , i.e., an absolute amount)

Vegetation Type	Sub-category	Mean	SE	References
Primary Tropical Forest (slash and burn)	Primary tropical forest	83.9	25.8	7, 15, 66, 3, 16, 17, 45
	Primary open tropical forest	163.6	52.1	21,
	Primary tropical moist forest	160.4	11.8	37, 73
	Primary tropical dry forest	-	-	66
All primary tropical forests		**119.6**	**50.7**	
Secondary tropical forest (slash and burn)	Young secondary tropical forest (3-5 yrs)	8.1	-	61
	Intermediate secondary tropical forest (6-10 yrs)	41.1	27.4	61, 35
	Advanced secondary tropical forest (14-17 yrs)	46.4	8.0	61, 73
All secondary tropical forests		**42.2**	**23.6**	66, 30
All Tertiary tropical forest		**54.1**	-	66, 30
All Shrublands		**14.3**	**9.0**	
Savanna Woodlands (early dry season burns)*	Savanna woodland	2.5	-	28
	Savanna parkland	2.7	-	57
All savanna grasslands (mid/late dry season burns)*		10.0	10.1	

Emissions from biomass burning

Default emission factors for different types of burning can be found in the table 2.5:

TABLE 2.5

EMISSION FACTORS ($g\ kg^{-1}$ DRY MATTER BURNED) FOR VARIOUS TYPES OF BURNING. VALUES ARE MEANS ± SD AND ARE BASED ON THE COMPREHENSIVE REVIEW BY ANDREAE AND MERLET (2001)

(To be used as quantity 'G_{ef}' in Equation 2.27)

	CO_2	CO	CH_4	N_2O	NO_X
Savanna and grassland	1613 ± 95	65 ± 20	2.3 ± 0.9	0.21 ± 0.10	3.9 ± 2.4
Agricultural residues	1515 ± 177	92 ± 84	2.7	0.07	2.5 ± 1.0
Tropical forest	1580 ± 90	104 ± 20	6.8 ± 2.0	0.20	1.6 ± 0.7
Extra tropical forest	1569 ± 131	107 ± 37	4.7 ± 1.9	0.26 ±0.07	3.0 ± 1.4
Biofuel burning	1550 ± 95	78 ± 31	6.1 ± 2.2	0.06	1.1 ± 0.6

Note: The "extra tropical forest' category includes all other forest types.

Note: For combustion of non-woody biomass in Grassland and Cropland, CO_2 emissions do not need to be estimated and reported, because it is assumed that annual CO_2 removals (through growth) and emissions (whether by decay or fire) by biomass are in balance (see earlier discussion on synchrony in Section 2.4.

Emissions from biomass burning

Default combustion factor values for different vegetation types can be found in the table 2.6:

TABLE 2.6
COMBUSTION FACTOR VALUES (PROPORTION OF PREFIRE FUEL BIOMASS CONSUMED) FOR FIRES IN A RANGE OF VEGETATION TYPES
(Values in column 'mean' are to be used for quantity C_f in Equation 2.27)

Vegetation Type	Sub-category	Mean	SD	References
Primary Tropical Forest (slash and burn)	Primary tropical forest	0.32	0.12	7, 8, 15, 56, 66, 3, 16, 53, 17, 45,
	Primary open tropical forest	0.45	0.09	21
	Primary tropical moist forest	0.50	0.03	37, 73
	Primary tropical dry forest	-	-	66
All primary tropical forests		**0.36**	**0.13**	
Secondary tropical forest (slash and burn)	Young secondary tropical forest (3-5 yrs)	0.46	-	61
	Intermediate secondary tropical forest (6-10 yrs)	0.67	0.21	61, 35
	Advanced secondary tropical forest (14-17 yrs)	0.50	0.10	61, 73
All secondary tropical forests		**0.55**	**0.06**	56, 66, 34, 30
All Tertiary tropical forest		**0.59**	-	66, 30
All Shrublands		**0.72**	**0.25**	
Savanna Woodlands (early dry season burns)*	Savanna woodland	0.22	-	28
	Savanna parkland	0.73	-	57
	Other savanna woodlands	0.37	0.19	22, 29

Emissions from biomass burning

Activity data: forest land

Estimates of area burnt in *Forest land* and in *land converting to Forest land* are needed.

A global database exists that covers the area burnt annually by fires but this will not provide reliable data for the area burnt annually by prescribed fires in individual countries.

It is good practice to develop national estimates of the area burned and the nature of the fires especially how they affect forest carbon dynamics (e.g., effects on tree mortality) to improve the reliability of national inventories.

Countries using **Tier 2** are likely to have access to national estimates.

Tier 3 estimation requires regional and forest type specific estimates of area subjected to fire and fire intensity.

Emissions from biomass burning

Activity data: Cropland remaining Cropland

Non-CO_2 emissions from *Cropland remaining Cropland* are usually associated with burning of agriculture residues, which vary by country, crop, and management system. CO_2 emissions from biomass burning do not have to be reported, since the carbon released during the combustion process is assumed to be reabsorbed by the vegetation during the next growing season.

The percentage of the agricultural crop residues burned 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.), to avoid possible double counting.

Tier 1: estimates of land areas under the crop types for which agricultural residues are normally burned; data cab be collected from national statistics, from remote sensed data or deduced from the annual crop production. If no national estimates are available, FAO statistics can be used.

Tier 2: requires more disaggregated area estimates (e.g., major crop types by climate zones) with country- crop management system specific residue accumulation rates.

Tier 3: requires high-resolution activity data disaggregated at sub-national to fine grid scales (i.e. specific types of crops by major climate and soil categories).

Emissions from biomass burning

Activity data: land converting to Cropland

Countries shall stratify the area converted to *Cropland*, by the previous land use (i.e. *Forest land* or *Grassland*), since the amount of fuel available for burning may present large variations from one category of land use to another.

Tier 1: estimates of land areas converted to Cropland from initial land uses (*Forest land, Grassland* etc.). The conversion should be estimated on a yearly basis. Estimates can be derived by applying a rate of conversion to *Cropland* to the total area cropped annually. The rate can be estimated on the basis of historical knowledge, judgment of country experts, and/or from samples of converted areas and assessment of the final land use. Alternatively, international data sources (FAO) may be used.

Tier 2: use actual area estimates for all possible conversions to *Cropland*. A multi-temporal remote sensed data analysis may be used (full coverage of the territory or representative sample areas), from which estimates of the area converted to Cropland in the entire territory can be derived.

Tier 3: total annual area converted to *Cropland* is estimated on the basis of Approach 3 (IPCC 2006 – chap. 3; spatially-explicit land use conversion data). It is good practice to develop a land-use change matrix, in a spatially explicit manner. The data should be disaggregated according to type of biome, climate, soils, political boundaries, or a combination of these parameters.

Emissions from biomass burning

Activity data: Grassland remaining Grassland

Non-CO_2 emissions from biomass burning in *Grassland remaining Grassland* result predominantly from *savannah burning*, which occurs mostly in tropical and sub-tropical regions. CO_2 emissions from biomass burning in *Grassland remaining Grassland* are not reported since they are largely balanced by the CO_2 that is reincorporated back into biomass via photosynthetic activity, within weeks to few years after burning.

Tier 1: the only activity data needed is the area affected by biomass burning in *Grassland remaining Grassland*. If national data on burnt areas are not available, data from global fire maps can be used. Countries may also estimate the annual area burnt by multiplying the area of *grassland* in the territory by the estimated annual fraction of grassland burnt, and to divide up the area thus estimated between *Grassland remaining Grassland* and *Grassland converted to other Land use.*

Tier 2: The *grassland* areas should be stratified according to different *grassland* vegetation types (shrublands, savanna grassland, savanna woodland etc.) and by sub-categories. National estimates of the area burned should be produced.

Tier 3: requires high-resolution activity data disaggregated at sub-national to fine grid scales. Similar to Tier 2, the *grassland* area should be stratified by specific vegetation types and sub-categories to be used in models.

Emissions from biomass burning

Activity data: land converted to Grassland

Greenhouse gas emissions from *Land converted to Grassland* occur from combustion of biomass and DOM in *Land converted to Grassland*. The activity data needed refers to the area affected by this activity. Countries shall stratify the area converted to grassland by forest land and cropland converted, since the amount of fuel available for burning may vary markedly from one category of land use to another.

Tier 1: burnt areas converted to *grassland* from initial land uses (*forest land, cropland* etc.) have to be estimated on a yearly basis. The estimates can be derived from:

1. applying a rate of conversion to grassland to the total annual area converted (The rate can be estimated on the basis of historical knowledge, expert judgment, and/or from samples of converted areas and assessment of the final land use);
2. using data from international sources, such as FAO, to estimate the area of forest land and cropland annually converted, and using expert judgment to estimate the portion of this area converted to grassland.

Tier 2: use actual area estimates for all possible conversions to *Grassland*. A multi-temporal remote sensed data analysis may be used (full coverage of the territory or representative sample areas), from which estimates of the area converted to *Grassland* in the entire territory can be derived.

Tier 3: total annual area converted to grassland has to be estimated. The data should be disaggregated according with type of biome, climate, political boundaries, or a combination of these parameters.

Thanks for your attention