The American Carbon Registry™

Tool for Tier I Estimation of Emissions from Livestock Management Project Activities[1]

SUPPORTING DOCUMENTATION FOR DATA AND EQUATIONS

Version 1.0

August 2014

[1] This Tool and the supporting documentation were developed as part of, and is incorporated in, ACR's *Grazing Land and Livestock Management (GLLM)* methodology. It is here published for ease of use as a separate stand-alone tool, but should be utilized as part of the GLLM methodology, and any others in which it is referenced.

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1. Background

The purpose of this document is to outline the methodology and data used in developing the *Tool for Tier I Estimation of Emissions from Livestock Management Project Activities* (referred to as A-MICROSCALE in the ACR methodology for *Grazing Land and Livestock Management (GLLM)*). The tool synthesizes annual estimates of net GHG reductions achieved per year from changing grazing land and livestock management activities in each of five SSRs (sources, sinks and reservoirs): enteric methane, manure methane, nitrous oxide from fertilizer use, fossil fuel emissions, and biotic sequestration in above- and belowground biomass and soils. IPCC Tier 1 and 2 equations from the 2006 Guidelines for Agriculture, Forestry and Other Land Use (AFOLU) form the basis of the calculations and are elaborated in the sections below.

The tool is designed as an Excel spreadsheet with multiple tabs. Each tab contains cells that are color coded; the blue cells are those into which the user is expected to enter data. Please note that a couple of the tabs utilize macros within Excel. Upon opening, please 'enable macros' if given the option.

2. Biotic Sequestration

2.1 Data Inputs

The biotic sequestration module applies IPCC Tier 1 data and equations to estimate carbon that accumulates in both aboveground biomass and soil as a result of a change in land use and/or land management. The only quantitative data required in the biotic sequestration module is the **size of the project area**, in hectares (or acres). Other data inputs are selected by the user from dropdown menus (Table 1), and the Excel tool specifies descriptions/definitions for each option.

Table 1. Parameters used in default calculations of annual carbon sequestration in soils and biomass.

Biotic Sequestration Parameter*	Dropdown Menu Options
Project Size	User-defined
Geographic Region	Africa, Asia, Eastern Europe, Indian Subcontinent, Latin America, Middle East, North America, Oceania, Western Europe
Climate Region	Tropical Montane, Tropical Wet, Tropical Moist, Tropical Dry, Warm Temperate Moist, Warm Temperate Dry, Cool Temperate Moist, Cool Temperate Dry, Boreal Moist, Boreal Dry
Soil Type	If outside the U.S.: High Activity Clay, Low Activity Clay, Sandy, Spodic, Volcanic, Wetlands

	If within the U.S.: Statsgo soil series names
Land Cover Type	Grassland/Rangeland, Long-Term Cultivated Crop, Short-Term Set Aside
Management Type	*Grassland*: Nominally Managed, Moderately Degraded, Severely Degraded, Improved *Cropland*: Full Tillage, Reduced Till, No Till
Management Inputs	Grassland: Medium, High Cropland: Low, Medium, High With Manure, High Without Manure
Tree planting included in project?	Yes or No

* The choices for geographical area, climate region, soil type, land cover type, management type, and management inputs follow the terminology and definitions from IPCC.

2.2 Equations

Under both baseline and project scenarios, a reference soil carbon stock is modified by factors that are determined by the climate zone, soil type, and set of management systems present in the project area. The annual change in organic carbon stocks in mineral soils are calculated as:

$$\Delta C_{Mineral} = \frac{SOC_B - SOC_P}{D} \qquad \textbf{(1)}$$

Where:

- $\Delta C_{Mineral}$ = annual change in carbon stocks in mineral soils, t C yr^{-1}
- SOC_B = soil organic carbon stock in the baseline scenario, t C
- SOC_P = soil organic carbon stock in the project scenario, t C
- D = time dependence of stock change factors, or the default time period for transition between equilibrium SOC values, yr (IPCC default of 20 years was applied)

The reference carbon stocks in both baseline and project scenarios are calculated according to Equation 2 below. Stock change factors for land-use system, management regime, and input of organic matter will differ between baseline and project scenarios. Annual carbon sequestration resulting from project activities is estimated as $1/20^{th}$ of the total change in carbon stock (i.e., *D* in Eq. 1 above is set to 20 years).

$$SOC = SOC_{REF_{c,s,i}} \bullet F_{LU_{c,s,i}} \bullet F_{MG_{c,s,i}} \bullet F_{I_{c,s,i}} \bullet A_{c,s,i} \qquad \textbf{(2)}$$

Where:

- SOC_{REF} = the reference carbon stock; t C ha^{-1}
- F_{LU} = stock change factor for land-use systems or sub-system for a particular land use, dimensionless
- F_{MG} = stock change factor for management regime, dimensionless
- F_I = stock change factor for input of organic matter, dimensionless

A = land area of the project

Default values for reference soil carbon stocks for mineral soils in the top 30 cm as well as default land use, management and input factors for grassland and cropland management systems are listed in Appendix 1.

In cases where trees are planted in the project area, the user is required to input the area over which plantings occur, a value that may be the same or different from the total size of the project area. Average carbon accumulation rates in trees planted as part of the project activity are estimated using default IPCC Tier 1 rates that vary by geographic region and climate region. Total biomass accumulation in the project area is therefore estimated as the product of the average biomass accumulation rate (in t C ha^{-1} yr^{-1}) and the land area over which trees are planted (ha). Default values for biomass accumulation are listed in Appendix 1.

3. Enteric Fermentation

3.1 Data Inputs

The enteric fermentation module applies IPCC Tier 2 equations to estimate changes in methane production as a result of a change in herd management. IPCC Tier 1 default values are built in for certain parameters, but a user can apply project-specific values if desired.
Enteric methane production in both the baseline and project scenarios is calculated based on the estimation of gross energy intake (GEI) of the herd (in MJ $head^{-1}$ day^{-1} per livestock type) multiplied by a methane conversion factor. Data inputs required to be entered by the user are listed in Table 2. Annual emission reductions are calculated as the difference in annual methane emissions between baseline and project scenarios.

Table 2. Parameters used in default calculations of enteric methane production.

Enteric Fermentation Parameter	Description
Number of animals produced per year	Broken down by animal subcategory: dairy cows, mature females, mature males, calves on milk, calves on forage, growing heifers/steers, replacement/growing, feedlot cattle. To facilitate estimation, monthly values can be entered so that a user can account for changes in herd number and transitions among subcategories within the herd based on time of year.
% of females giving birth in a year	Collected only for mature cattle.
Feeding situation	The feeding situation that most accurately represents the animal subcategory must be determined (stall, pasture, grazing large areas).
Average weight of animal	Live-weight data should be collected for each animal subcategory. It is unrealistic to perform a complete census

	of live-weights, so live-weight data should be obtained from representative sample studies or statistical databases if these already exist. Comparing live-weight data with slaughter-weight data is a useful cross-check to assess whether the live-weight data are representative of farm conditions. However, slaughter-weight data should not be used in place of live-weight data as it fails to account for the complete weight of the animal. Additionally, it should be noted that the relationships between live-weight and slaughter-weight varies with breed and body condition. For cattle, the yearly average weight for each animal category (e.g., mature beef cows) is needed.
Average daily weight gain	Data on average weight gain are generally collected for feedlot animals and young growing animals. Mature animals are generally assumed to have no net weight gain or loss over an entire year. Mature animals frequently lose weight during the dry season or during temperature extremes and gain weight during the following season. However, increased emissions associated with this weight change are likely to be small. Reduced intakes and emissions associated with weight loss are largely balanced by increased intakes and emissions during the periods of gain in body weight.
Annual Milk Production	These data are for milking dairy cows.
Fat content of milk	Average fat content of milk is required for lactating cows producing milk for human consumption.
Mean daily temperature during winter season (if <20 C)	Detailed feed intake models adapted from North America data suggest adjusting the coefficient for calculating net energy for maintenance requirements of open-lot fed cattle in colder climates. Considering the average temperature during winter months, net energy for maintenance requirements may increase by as much as 30% in northern North America. This increase in feed use for maintenance is also likely associated with greater methane emissions.
Average mature weight of an adult female	The mature weight of the adult animal of the inventoried group is required to define a growth pattern, including the feed and energy required for growth. For example, mature weight of a breed or category of cattle is generally considered to be the body weight at which skeletal development is complete. The mature weight will vary

	among breeds and should reflect the animal's weight when in moderate body condition. This is termed 'reference weight' or 'final shrunk body weight'.

3.2 Equations

3.2.1 Gross Energy Intake Calculations

Table 3 presents a summary of the equations used to estimate daily gross energy intake for cattle. The output value, gross energy intake in MJ day^{-1}, is used for estimating methane emissions from enteric fermentation under both baseline and project scenarios and also for estimating the quantity of manure produced by the herd, which enters into the manure management emission calculations (Section 4 below). The equations and text are taken directly from Chapter 10 of the 2006 IPCC Guidelines for Agriculture, Forestry and Other Land Use (AFOLU).

Table 3. Summary of equations used to estimate daily gross energy intake. From Chapter 10 of 2006 IPCC Guidelines.

Metabolic functions and other estimates	IPCC Equation	Equation in this Document
Maintenance (NE_m)	10.3	3
Activity (NE_a)	10.4	5
Growth (NE_g)	10.6	6
Lactation (NE_l)*	10.8	7
Pregnancy (NE_p)*	10.13	8
Ratio of net energy available in diet for maintenance to digestible energy consumed (REM)	10.14	9
Ratio of net energy available for growth in a diet to digestible energy consumed (REG)	10.15	10
Gross Energy	10.16	11

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

Net energy for maintenance: (NE_m) is the net energy required for maintenance, which is the amount of energy needed to keep the animal in equilibrium where body energy is neither gained nor lost. Cf_i is defined as 0.322 for non-lactating cows, 0.386 for lactating cows, and 0.370 for bulls.

$$NE_m = Cf_i \bullet (Weight)^{0.75} \quad \textbf{(3)}$$

Where:

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

Cf_i	= a coefficient that varies for each animal category, MJ day^{-1} kg^{-1}
Weight	= live-weight of animal, kg

The coefficient in Equation (3) (Cf_i) is adjusted for cattle in colder climates (<20°C) to reflect the higher maintenance energy requirements (Equation 4):

$$Cf_i(in\_cold) = Cf_i + 0.0048 \bullet (20 - °C) \quad \textbf{(4)}$$

Where:

Cf_i	= a coefficient that varies for each animal category, MJ day^{-1} kg^{-1}
°C	= mean daily temperature during winter season (if <20°C)

Net energy for activity: (NE_a) is the net energy for activity, or the energy needed for animals to obtain their food, water and shelter. It is based on its feeding situation rather than characteristics. If a mixture of feeding situations occurs during the year, NE_a is weighted accordingly in the calculations.

$$NE_a = C_a \bullet NE_m \quad \textbf{(5)}$$

Where:

NE_a	= net energy for animal activity, MJ day^{-1}
C_a	= coefficient corresponding to animal's feeding situation (Table 4)
NE_m	= net energy required by the animal for maintenance (Equation 3)

Table 4. Activity coefficients corresponding to animal's feeding situation. From Chapter 10 of 2006 IPCC Guidelines

Feeding Situation	Definition	C_a
Stall	Animals are confined to a small area (i.e., tethered, pen, barn) with the result that they expend very little or no energy to acquire feed	0.00
Pasture	Animals are confined in areas with sufficient forage requiring modest energy expense to acquire feed	0.17
Grazing large regions	Animals graze in open range land or hilly terrain and expend significant energy to acquire feed	0.36

Net energy for growth: (NE_g) is the net energy needed for growth (i.e., weight gain). Constants for conversion from calories to joules and live to shrunk and empty body weight have been incorporated into the equation.

$$NE_g = 22.02 \bullet \left(\frac{BW}{C \bullet MW} \right)^{0.75} \bullet WG^{1.097} \quad \textbf{(6)}$$

Where:
NE_g = net energy needed for growth, MJ day^{-1}
BW = the average live body weight (BW) of the animals in the population, kg
C = a coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls
MW = the mature live body weight of an adult female in moderate body condition, kg
WG = the average daily weight gain of the animals in the population, kg day^{-1}

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

$$NE_l = Milk \bullet (1.47 + 0.40 \bullet Fat) \quad \textbf{(7)}$$

Where:
NE_l = net energy for lactation, MJ day^{-1}
Milk = amount of milk produced, kg of milk day^{-1}
Fat = fat content of milk, % by weight

Net energy for pregnancy: (NE_p) is the energy required for pregnancy. For cattle, the total energy requirement for pregnancy for a 281 day gestation period averaged over an entire year is calculated as 10% of NE_m. When using NE_p to calculate *GE*, the NE_p estimate must be weighted by the portion of the mature females that actually go through gestation in a year. For example, if 80% of the mature females in the animal category give birth in a year, then 80% of the NE_p values would be used in the GE equation.

$$NE_p = C_{pregnancy} \bullet NE_m \quad \textbf{(8)}$$

Where:

NE_p = net energy required for pregnancy, MJ day^{-1}
$C_{pregnancy}$ = pregnancy coefficient
NE_m = net energy required by the animal for maintenance (Equation 3), MJ day^{-1}

Ratio of net energy available in diet for maintenance to digestible energy consumed (REM): For cattle, the ratio of net energy available in a diet for maintenance to digestible energy consumed (REM) is estimated using the following equation:

$$REM = \left[1.123 - (4.092 \bullet 10^{-3} \bullet DE\%) + \left[1.126 \bullet 10^{-5} \bullet (DE\%)^2\right] - \left(\frac{25.4}{DE\%}\right)\right] \quad \textbf{(9)}$$

Where:
REM = ratio of net energy available in a diet for maintenance to digestible energy consumed
DE% = digestible energy expressed as a percentage of gross energy

Ratio of net energy available for growth in a diet to digestible energy consumed (REG): For cattle, the ratio of net energy available for growth in a diet to digestible energy consumed (REG) is estimated using the following equation:

$$REG = \left[1.164 - (5.160 \bullet 10^{-3} \bullet DE\%) + \left[1.308 \bullet 10^{-5} \bullet (DE\%)^2\right] - \left(\frac{37.4}{DE\%}\right)\right] \quad \textbf{(10)}$$

Where:
REG = ratio of net energy available for growth in a diet to digestible energy consumed
DE% = digestible energy expressed as a percentage of gross energy

Gross energy (GE): The GE requirement is derived based on the summed net energy requirements and the energy availability characteristics of the feed(s).

$$GE = \frac{\left(\frac{NE_m + NE_a + NE_l + NE_p}{REM}\right) + \left(\frac{NE_g}{REG}\right)}{\frac{DE\%}{100}} \quad \textbf{(11)}$$

Where:
GE = gross energy, MJ day^{-1}
NE_m = net energy required by the animal for maintenance (Equation 3), MJ day^{-1}
NE_a = net energy for animal activity (Equation 5), MJ day^{-1}
NE_l = net energy for lactation (Equation 7), MJ day^{-1}
NE_p = net energy required for pregnancy (Equation 8), MJ day^{-1}
REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation 9)
NE_g = net energy needed for growth (Equation 6), MJ day^{-1}
REG = ratio of net energy available for growth in a diet to digestible energy consumed (Equation 10)
DE% = digestible energy expressed as a percentage of gross energy

Feed digestibility defaults used for calculating REM and REG are listed in Table 5 and are based on typical digestibility values for a range of diet types. For ruminants, common ranges of feed digestibility are 45-55% for crop by-products and range lands; 55-75% for good pastures, good preserved forages, and grain supplemented forage based diets; and 75-85% for grain-based diets fed in feedlots. Variations in diet digestibility results in major variations in the estimate of feed needed to meet animal requirements and consequently associated methane emissions and amounts of manure excreted. It is also important to note that digestibility, intake, and growth are co-dependent phenomena. For example, a low digestibility will lead to lower feed intake and consequently reduced growth. A 10% error in estimated DE will be magnified to 12 to 20% when estimating methane emissions and even more (20 to 45%) for manure excretion (volatile solids).

Table 5. Representative feed digestibility for various management conditions. From Chapter 10 of 2006 IPCC Guidelines

Management Type	Diet	Estimated DE%
Confined	>90% concentrate feed	80
	Forage	50
Grazing	Pasture	65

3.2.2 Methane Emissions from Enteric Fermentation

The extent to which feed energy is converted to CH_4 depends on several interacting feed and animal factors. A methane conversion factor of zero is assumed for all juveniles consuming only milk, 3.0% for feedlot fed cattle, and 6.5% for all other situations.

A methane emission factor per animal category is calculated based on estimates of gross energy (calculated in Section 3.2.1) and a methane conversion factor (Y_m):

$$EF = \left[\frac{GE \bullet \left(\frac{Ym}{100} \right) \bullet 365}{55.65} \right] \quad \textbf{(12)}$$

Where:
EF = emission factor, kg CH4 head^{-1} yr^{-1}
GE = gross energy intake, MJ head^{-1} yr^{-1}
Ym = methane conversion factor, percent of gross energy in feed converted to methane
The factor 55.65 (MJ/kg CH_4) is the energy content of methane

To estimate total emissions, the selected emission factors are multiplied by the associated animal populations and summed.

4 Manure Management

This section describes equations for estimating methane and nitrous oxide emissions produced during the storage and treatment of manure, and from manure deposited on pasture, under both baseline and project scenarios. The term 'manure' is used here collectively to include both dung and urine (i.e., the solids and the liquids) produced by livestock. The decomposition of manure under anaerobic conditions (i.e., in the absence of oxygen), during storage and treatment, produces CH_4. These conditions occur most readily when large numbers of animals are managed in a confined area (e.g., dairy farms, beef feedlots) and where manure is disposed of in liquid-based systems.

4.1 Data Inputs

The main factors affecting CH_4 emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically. The former depends on the rate of waste production per animal and the number of animals, and the latter on how the manure is managed. When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it decomposes anaerobically and can produce a significant quantity of CH_4. The temperature and the retention time of the storage unit greatly affect the amount of methane produced. When manure is handled as a solid (e.g., in stacks or piles) or when it is deposited on pastures and rangelands, it tends to decompose under more aerobic conditions and less CH_4 is produced.

In the enteric fermentation tab, the user is required to enter data that is used to calculate gross energy intake. These data and calculations are carried over into the manure management spreadsheet and are not required to be entered again. New data to be provided by the user for manure management are **geographic region**, **average annual temperature** and the **percentage of total manure managed under different manure management systems** under both baseline and project scenarios. Annual emission reductions are calculated as the difference in total annual CH_4 and N_2O emissions between baseline and project scenarios.

4.2 Equations

4.2.1 CH_4 emissions

The calculations rely on two primary types of inputs that affect the calculation of methane emission factors from manure, and these equations are calculated automatically in the tool:

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. *Bo* varies by animal species and feed regimen and is a theoretical methane yield based on the amount of VS in the manure.

Volatile solids (VS) are the organic material in livestock manure and consist of both biodegradable and nonbiodegradable fractions. The *VS* content of manure equals the fraction of the diet consumed that is not digested and thus excreted as fecal material which, when combined with urinary excretions, constitutes manure. The *VS* excretion rate is estimated as:

$$VS = \left[GE \bullet \left(1 - \frac{DE\%}{100} \right) + (UE \bullet GE) \right] \bullet \left[\left(\frac{1 - ASH}{18.45} \right) \right] \quad (13)$$

Where:

VS = Volatile solid excretion per day on a dry-organic matter basis, kg VS day^{-1}
GE = Gross energy intake, MJ day^{-1}
DE% = Digestibility of the feed in percent (e.g., 60%)
(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)
ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle)
18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg^{-1}). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

The digestibility of the feed *(DE%)* is determined by feed type, listed in Table 5 above. Gross energy intake is calculated using Equation 11 above.

Bo values (Bo) are the maximum methane-producing capacity of the manure. *Bo* values were specified in the tool by continental region according to values listed in Table 6.

Table 6. *Bo* values for dairy and other cattle. From Chapter 10 of 2006 IPCC Guidelines

Region	*Bo* Dairy Cows	*Bo* Other Cattle
North America	0.24	0.19
Western Europe	0.24	0.18
Eastern Europe	0.24	0.17
Oceania	0.24	0.17
Latin America	0.13	0.1

Africa	0.13	0.1
Middle East	0.13	0.1
Asia	0.13	0.1
Indian Subcontinent	0.13	0.1

Manure management system characteristics: System-specific methane conversion factors *(MCF)* reflect the portion of *Bo* that is achieved. The system *MCF* varies with the manner in which the manure is managed and the climate, and can theoretically range from 0 to 100%. Both temperature and retention time play an important role in the calculation of the *MCF*.

A weighted average *MCF* value is calculated using the user-defined estimates of the total manure managed by each waste system. 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. *MCF*s are listed in Appendix 2.

$$EF_{(T)} = (VS_{(T)} \bullet 365) \bullet \left[B_{o(T)} \bullet 0.67 \bullet \sum_{S,k} \frac{MCF_{S,k}}{100} \bullet MS_{(S,k)} \right] \quad \textbf{(14)}$$

Where:

EF = annual CH_4 emission factor for livestock category T, kg CH_4 animal^{-1} yr^{-1}
VS = daily volatile solid excreted for livestock category T, kg dry matter animal^{-1} day^{-1}
365 = basis for calculating annual VS production, days yr^{-1}
$Bo_{(T)}$ = maximum methane producing capacity for manure produced by livestock category T, m^3 CH_4 kg^{-1} of VS excreted
0.67 = conversion factor of m^3 CH_4 to kilograms CH_4
$MCF_{(S,k)}$ = methane conversion factors for each manure management system S by climate region *k*, %
$MS_{(T,S,k)}$ = fraction of livestock category *T*’s manure handled using manure management system *S* in climate region *k*, dimensionless

To estimate total emissions, the selected emission factors are multiplied by the associated animal populations and summed.

4.2.2 N_2O emissions

N_2O emissions from manure management are calculated using IPCC Tier 1 methods and are calculated as the sum of direct and indirect emissions from volatilization. Direct emissions occur via combined nitrification and denitrification of nitrogen contained in the manure. Indirect emissions result from N volatilization as well as from runoff and leaching into soils from the solid storage of manure at outdoor areas, in feedlots and where animals are grazing in pastures. Only direct emissions and indirect emissions from volatilization are included here; indirect emissions from runoff/leaching are not included in the estimates because there are extremely limited measurement data on leaching and runoff losses from various manure management systems.

Direct emissions from manure management are calculated as:

$$N_2O_D = \left[\sum_S \left[\sum_T (N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)} \right] \bullet EF_{3(S)} \right] \bullet \frac{44}{28} \quad \textbf{(15)}$$

Where:

N_2O_D = direct N_2O emissions from manure management; kg N_2O yr^{-1}
$N_{(T)}$ = number of head of livestock species/category *T*
$Nex_{(T)}$ = annual average N excretion per head of species/category *T*, kg N $animal^{-1}$ yr^{-1}
$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock category T that is managed in manure management system S, dimensionless
$EF_{3(S)}$ = emission factor for direct N_2O emissions from manure management system *S*, kg N_2O-N/kg N in manure management system *S*

The annual average nitrogen excretion rates per livestock type *T* ($Nex_{(T)}$) are calculated as:

$$Nex_{(T)} = N_{rate(T)} \bullet \frac{TAM}{1000} \bullet 365$$

Where:
$N_{ex(T)}$ = annual N excretion for livestock category *T*, kg N $animal^{-1}$ yr^{-1}
$N_{rate(T)}$ = default N excretion rate, kg N (1000 kg animal mass)$^{-1}$
$TAM_{(T)}$ = typical animal mass for livestock category *T*, kg $animal^{-1}$

Default values for nitrogen excretion rate are given in Table 7 and default values for typical animal mass are given in Table 8.

Table 7. Default nitrogen excretion rates for cattle in different geographic regions, kg N (1000 kg animal mass)$^{-1}$ day^{-1}. From Chapter 10 of 2006 IPCC Guidelines

Region	Dairy Cattle	Other Cattle
North America	0.44	0.31

Western Europe	0.48	0.33
Eastern Europe	0.35	0.35
Oceania	0.44	0.50
Latin America	0.48	0.36
Africa	0.60	0.63
Middle East	0.70	0.79
Asia	0.47	0.34

Table 8. Default animal mass values for cattle in different geographic regions, in kg. From Chapter 10 of 2006 IPCC Guidelines

Region	Dairy Cattle	Other Cattle
North America	604	389
Western Europe	600	420
Eastern Europe	550	391
Oceania	500	330
Latin America	400	305
Africa	275	173
Middle East	275	173
Asia	350	319
Indian Subcontinent	275	110

Default emission factors for direct N_2O emissions from manure management system S (EF_3) are listed in Appendix 3.

Indirect emissions from volatilization of N in forms of NH_3 and NO_x ($N_2O_{G(mm)}$) are calculated as:

$$N_2O_{G(mm)} = (N_{volatilization-MMS} \bullet EF_4) \bullet \frac{44}{28} \qquad \textbf{(16)}$$

Where:

$N_2O_{G(mm)}$ = indirect N_2O emissions due to volatilization of N from manure management, 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 + NOx-N volatilized)-1; default value is 0.01, given in Chapter 11, Table 11.3

The amount of manure nitrogen lost to volatilization of NH_3 and NO_x is calculated as:

$$N_{volatilization-MMS} = \sum_{S}\left[\sum_{T}\left[\left(N_{(t)} \bullet Nex_{(T)} \bullet MS_{(T,S)}\right) \bullet \left(\frac{Frac_{Gas\,MS}}{100}\right)\right]_{(T,S)}\right] \quad (17)$$

Where:

$N_{volatilization\text{-}MMS}$ = amount of manure nitrogen that is lost due to volatilization of NH_3 and NO_x, kg N yr^{-1}

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

$Nex_{(T)}$ = annual average N excretion per head of species/category *T*, 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*, 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*, %

Default values for $Frac_{GasMS}$ are listed in Table 9.

Table 9. Default values for nitrogen loss due to volatilization of NH_3 and NO_x from manure management. From Chapter 10 of 2006 IPCC Guidelines

Manure Management System	Dairy Cows	Other cattle
Anaerobic lagoon	35%	
Liquid/Slurry	40%	
Pit storage	28%	
Dry lot	20%	30%
Solid storage	30%	45%
Daily spread	7%	
Deep bedding		30%

5 Fertilizer Management

5.1 Data Inputs

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/released), and through two indirect pathways: (i) following volatilization of NH_3 and NO_x from managed soils and from fossil fuel combustion and biomass burning, and the subsequent redeposition of these gases and their products NH_4^+ and NO_3^- to soils and waters; and (ii) after leaching and runoff of N, mainly as NO_3^- from managed soils.

The A-MICROSCALE tool addresses direct emissions from fertilizer (synthetic and organic), atmospheric deposition, leaching, and emissions associated with fertilizer production. At this time, the annual amount of N in crop residues and the amount of N in mineral soils that is mineralized in association with loss of soil C from soil organic matter as a result of changes to land use or management is not included in the estimates.

The user is required to enter data on the quantity and type of synthetic fertilizers applied, the area of land where fertilizer is applied, and the percentage of managed manure applied to fields under both the baseline and project scenarios.

Annual emission reductions are calculated as the difference in total annual N_2O emissions between baseline and project scenarios.

5.2 Equations

5.2.1 Direct emissions

Direct N_2O emissions from managed soils are estimated as:

$$N_2O - N_{Ninputs} = \frac{(F_{SN} + F_{ON}) \bullet 0.01 \bullet \frac{44}{28} \bullet 310}{1000} \quad \textbf{(18)}$$

Where:

$N_2O\text{-}N_{inputs}$ = annual direct N_2O-N emissions from N inputs to managed soils; t CO_2e yr^{-1}
F_{SN} = annual amount of synthetic fertilizer N applied to soils, kg N yr^{-1}
F_{ON} = annual amount of animal manure applied to soils, kg N yr^{-1}
0.01 = emission factor for N_2O emissions from N inputs, kg N_2O-N (kg N input)$^{-1}$
44/28 = conversion of N_2O to CO_2
310 = Global Warming Potential of N_2O
1000 = conversion from kg to tons

The total amount of each type of synthetic fertilizer N applied to soils (F_{SN}) under both baseline and project scenarios is calculated as the product of the total weight of fertilizer applied and its percent nitrogen content.

Following storage or treatment in any system of manure management, nearly all the manure is typically applied to land. The emissions occurring from the urine and dung N deposited on pasture, range, paddock and by grazing animals is accounted under manure management. The emissions that subsequently arise from the application of managed manure to soil are reported as part of fertilizer emissions (F_{ON}). A significant portion of the total nitrogen excreted by animals in managed systems (i.e., all livestock except those in pasture and grazing conditions) is lost prior to final application to managed soils. In order to estimate the amount of animal manure nitrogen that is directly applied to soils, it is necessary to reduce the total amount of nitrogen excreted by animals in managed systems by the losses of N through volatilization, conversion to N_2O and losses through leaching and runoff. Where organic forms of bedding material (straw, sawdust, chippings, etc.) are used, the additional nitrogen from the bedding material should also be considered as part of the managed manure N applied to soils. Bedding is typically collected with the remaining manure and applied to soils. Since mineralization of nitrogen compounds in beddings occurs more slowly compared to manure and the concentration of ammonia fraction in organic beddings is negligible, both volatilization and leaching losses during storage area assumed to be zero.

The total amount of organic additions (F_{ON}) is assumed in A-MICROSCALE to be equal to the fraction of available managed manure nitrogen that is applied to managed soils. The total amount of managed manure nitrogen that is available for application is calculated as:

$$N_{MMS\_Avb} = \sum_{S}\left\{\sum_{(T)}\left[\left[(N_{(T)} \bullet Nex_{(T)} \bullet MS_{(T,S)}) \bullet \left(1 - \frac{Frac_{LossMS}}{100}\right)\right] + \left[N_{(T)} \bullet MS_{(T,S)} \bullet N_{beddingMS}\right]\right]\right\} \quad \textbf{(19)}$$

Where:

N_{MMS_Avb} = amount of managed manure nitrogen available for application to managed soil, kg N yr^{-1}
$N_{(T)}$ = number of head of livestock species/category *T*
$Nex_{(T)}$ = annual average N excretion per animal of species/category *T*, 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
$Frac_{LossMS}$ = amount of managed manure nitrogen for livestock category *T* that is lost in the manure management system S, %
$N_{beddingMS}$ = amount of nitrogen from bedding (to be applied for solid storage and deep bedding *MMS* if known organic bedding usage), kg N $animal^{-1}$ yr^{-1}
S = manure management system
T = species/category of livestock

The amount of managed manure nitrogen actually applied to soils is then calculated as:

$$F_{ON} = N_{MMS\_Avb} \bullet \frac{\%_{applied}}{100} \quad \textbf{(20)}$$

Where:

F_{ON} = annual amount of animal manure applied to soils, kg N yr^{-1}

N_{MMS_Avb} = amount of managed manure nitrogen available for application to managed soil, kg N yr^{-1}

%applied = percent of total managed manure applied to managed soils, %

5.2.2 Indirect emissions

Atmospheric deposition

The N_2O emissions from atmospheric deposition of N volatilized from managed soil are estimated as:

$$N_2O_{(ATD)} - N = \left[(F_{SN} \bullet Frac_{GASF}) + (F_{ON} \bullet Frac_{GASM})\right] \bullet EF_4 \quad \textbf{(21)}$$

Where:

$N_2O_{(ATD)}$-N = annual amount of N2O-N produced from atmospheric deposition of N volatilized from managed soils, kg N_2O-N yr^{-1}

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

$Frac_{GASF}$ = fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x, kg N volatilized (kg of N applied)$^{-1}$ (default value = 0.10)

F_{ON} = annual amount of animal manure additions applied to soils, kg N yr^{-1}

$Frac_{GASM}$ = fraction of applied organic N fertilizer materials (F_{ON}) that volatilizes as NH_3 and NO_x, kg N volatilized (kg of N applied)$^{-1}$ (default value = 0.20)

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 + NOx-N volatilized)$^{-1}$] (default value 0.01)

Conversion of $N_2O_{(ATD)}$-N emissions to CO_2e emissions is performed by using the following equation:

$$N_2O_{(ATD)} = \frac{N_2O_{(ATD)} - N \bullet \frac{44}{28} \bullet 310}{1000} \quad \textbf{(22)}$$

Leaching and runoff

N_2O emissions from leaching and runoff are estimated as:

$$N_2O_{(L)} - N = (F_{SN} + F_{ON}) \bullet Frac_{LEACH-(H)} \bullet EF_5 \quad \textbf{(23)}$$

Where:

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

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

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralized in managed soils in regions where leaching/runoff occurs 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)$^{-1}$ (default value 0.0075)

Conversion of *$N_2O_{(L)}$-N* emissions to CO_2e emissions is performed by using the following equation:

$$N_2O_{(L)} = \frac{N_2O_{(L)} - N \bullet \frac{44}{28} \bullet 310}{1000} \quad \textbf{(24)}$$

5.2.3 Fertilizer production

Emissions associated with the production of fertilizer used are estimated as:

$$\sum_F Area_F \bullet AppRate_F \bullet EF_{CO2,f} \quad \textbf{(25)}$$

Where:

$Area_F$ = area over which fertilizer *F* is applied; ha

$AppRate_F$ = Application rate of fertilizer *F*; t ha^{-1}

$EF_{CO2,f}$ = Emission factor for fertilizer *F*; t CO_2e (ton fertilizer)$^{-1}$

$EF_{CO2,f}$ is calculated following IPCC and CDM guidelines as follows (and as referenced in Section 5.3 of the ACR fertilizer methodology):

If the fertilizer used is urea, the $EF_{CO2,f}$ = 1.54 t CO_2e per ton urea based on IPCC default values shall be used, which takes into account the fact that the total GHG emissions from urea would be GHG emissions during ammonia production - intermediate CO2 storage in urea + CO2 release due to urea application (see 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3: Industrial Processes and Product Use; Chapter 3.2 Ammonia Production).

In case of other synthetic nitrogen fertilizers in the absence of reliable project specific data, conservative values may be calculated (as long as the mass ratio of N in the fertilizer is known) using the following formula:

$$EF_{CO2,f} = N_{contf} * 0.82 * 2.014 \quad \textbf{(26)}$$

Where

$EF_{CO2,f}$ = The emission factor for the production of fertilizer *f*; t CO_2 per ton fertilizer *f*
N_{contf} = The N content of fertilizer f on a mass ratio basis (see parameter table for examples for common synthetic N fertilizer types); %
0.82 = The mass ratio between N and NH_3
2.014 = A conservative emission factor for ammonia production; t CO_2 per ton NH_3

5.2.4 Urea fertilization

Adding urea to soils during fertilization leads to a loss of CO_2 that was fixed in the industrial production process. These emissions are estimated as:

$$CO_2 - CEmission = M \bullet EF \bullet \frac{44}{12} \quad \textbf{(27)}$$

Where:
CO_2*-C Emission* = annual C emissions from urea application, t CO_2 yr^{-1}
M = annual amount of urea fertilization, tonnes urea yr^{-1}
EF = emission factor, tonne of C $(\text{tonne of urea})^{-1}$, default = 0.2, which is equivalent to the carbon content of urea on an atomic weight basis.

6 Fossil Fuel Emissions

6.1 Data Inputs

The method for estimating emissions from fossil fuels is fuel-based, and emissions are estimated on the basis of the quantities of fuel combusted and average emission factors. For

CO_2, emission factors mainly depend upon the carbon content of the fuel. Therefore, CO_2 emissions can be estimated fairly accurately based on the total amount of each type of fuel combusted and the average carbon content of the fuel. Annual emission reductions are calculated as the difference in total annual CO_2 emissions between baseline and project scenarios.

6.2 Equations

Emissions are calculated from fuel consumption as follows:

$$E_{FC,t} = \sum_{a=1}^{A} \left(Fuel_{a,t} \times EF_a \right) \quad \textbf{(28)}$$

Where:

$E_{FC,t}$ — CO_2-e emissions of fuel consumption in year t; t CO_2-e

$Fuel_{a,t}$ — Amount of fuel of type a consumed in year t; terrajoule (TJ)

EF_a — Emission factor of fuel type a; t CO_2-e/TJ

a — 1,2,3,…A fuel types (e.g. diesel, gasoline, etc.)

The amount of fuel of a particular kind combusted in year t (Fuela,t) can be estimated as:

$$Fuel_{a,t} = \frac{Liters_{Fuel_{a,t}} \bullet Density_{Fuel_a} \bullet NCV_{Fuel,a}}{10^6} \quad \textbf{(29)}$$

Where:

$Fuel_{a,t}$ — Amount of fuel type *a* consumed in year *t*; TJ

$Liters_{Fuel\ a,t}$ — Quantity of fuel of type *a* consumed in year *t*; ltr

$Density_{Fuel\ a}$ — Density of fuel type *a*; kg/ltr

$NCV_{Fuel\ a}$ — Net calorific value of fuel type *a*; TJ/Gg

Default emission factors for a selection of different fuel types, the density of different fuels, and the net calorific value per fuel type are given in Table10.

Table 10. Default values of net calorific value, emission factors and density of different fossil fuel types.

Fuel Types	NCV (TJ/Gg)	EF (kg CO2/TJ)	Density (kg/m3)
Ethane	44.2	64200	366.3
Propane	44.2	64200	507.6
Butane	44.2	64200	572.7
LPG	44.2	64200	522.2
Motor Gasoline	44.3	69300	740.7
Aviation Gasoline (avgas)	44.3	70000	716.8
Other Kerosene	43.8	71900	802.6
Gas/Diesel Oil	43	74100	843.9
Charcoal	29.5	112000	
Biodiesel	27	70800	
Biogas	27	70800	
Other Liquid Biofuels	27.4	79600	
Sludge Gas	50.4	54600	
Lubricants (incl. motor oil)	40.2	73300	

Appendix 1: Default Values for Biotic Equations

Table A1. Default reference soil organic carbon stocks (SOC_{REF}) for mineral soils (t C ha^{-1} in 0-30 cm depth).

These values are applied to projects that reside outside of the U.S. For projects within the U.S., soil carbon values (t C ha-1 in 0-30 cm depth) are derived from STATSGO soil series information by state.

Climate Region	HAC soils[1]	LAC soils[2]	Sandy soils[3]	Spodic Soils[4]	Volcanic soils[5]	Wetland Soils[6]
Boreal	68	NA	10	117	20	146
Cold Temperate Dry	50	33	34	NA	20	
Cold Temperate Moist	95	85	71	115	130	87
Warm Temperate Dry	38	24	19	NA	70	
Warm Temperate Moist	88	63	34	NA	80	88
Tropical Dry	38	35	31	NA	50	
Tropical Moist	65	47	39	NA	70	
Tropical Wet	44	60	66	NA	130	
Tropical Montane	88*	63*	34*	NA	80*	86

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux et al. (2002). Mean stocks are shown. A nominal error estimate of ±90% (expressed as 2x standard deviations as percent of the mean) are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

* Data were not available to directly estimate reference C stocks for these soil types in the tropical montane climate so the stocks were based on estimates derived for the warm temperate, moist region, which has similar mean annual temperatures and precipitation.

[1] Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2] Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminum oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

[3] Includes all soils (regardless of taxonomic classification) having >70% sand and <8% clay, based on standard textural analyses (in WRB classification includes Arenosols; in USDA classification includes Psamments).

[4] Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5] Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

[6] Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

Table A2. Stock change factors for grasslands.

TABLE 6.2
RELATIVE STOCK CHANGE FACTORS FOR GRASSLAND MANAGEMENT

Factor	Level	Climate regime	IPCC default	Error [1,2]	Definition
Land use (F_{LU})	All	All	1.0	NA	All permanent grassland is assigned a land-use factor of 1.
Management (F_{MG})	Nominally managed (non –degraded)	All	1.0	NA	Represents non-degraded and sustainably managed grassland, but without significant management improvements.
Management (F_{MG})	Moderately degraded grassland	Temperate /Boreal	0.95	± 13%	Represents overgrazed or moderately degraded grassland, with somewhat reduced productivity (relative to the native or nominally managed grassland) and receiving no management inputs.
		Tropical	0.97	± 11%	
		Tropical Montane[3]	0.96	± 40%	
Management (F_{MG})	Severely degraded	All	0.7	± 40%	Implies major long-term loss of productivity and vegetation cover, due to severe mechanical damage to the vegetation and/or severe soil erosion.
Management (F_{MG})	Improved grassland	Temperate /Boreal	1.14	± 11%	Represents grassland which is sustainably managed with moderate grazing pressure and that receive at least one improvement (e.g., fertilization, species improvement, irrigation).
		Tropical	1.17	± 9%	
		Tropical Montane[3]	1.16	± 40%	
Input (applied only to improved grassland) (F_I)	Medium	All	1.0	NA	Applies to improved grassland where no additional management inputs have been used.
Input (applied only to improved grassland) (F_I)	High	All	1.11	± 7%	Applies to improved grassland where one or more additional management inputs/improvements have been used (beyond that is required to be classified as improved grassland).

[1] ± two standard deviations, expressed as a percent of the mean; where sufficient studies were not available for a statistical analysis a default, based on expert judgement, of ± 40% is used as a measure of the error. NA denotes 'Not Applicable', for factor values that constitute reference values or nominal practices for the input or management classes.

[2] This error range does not include potential systematic error due to small sample sizes that may not be representative of the true impact for all regions of the world.

[3] There were not enough studies to estimate stock change factors for mineral soils in the tropical montane climate region. As an approximation, the average stock change between the temperate and tropical regions was used to approximate the stock change for the tropical montane climate.

Note: See Annex 6A.1 for estimation of default stock change factors for mineral soil C emissions/removals for Grassland.

Table A3. Stock change factors for croplands.

TABLE 5.5
RELATIVE STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND

Factor value type	Level	Temperature regime	Moisture regime[1]	IPCC defaults	Error[2,3]	Description
Land use (F_{LU})	Long-term cultivated	Temperate/ Boreal	Dry	0.80	±9%	Represents area that has been continuously managed for >20 yrs, to predominantly annual crops. Input and tillage factors are also applied to estimate carbon stock changes. Land-use factor was estimated relative to use of full tillage and nominal ("medium") carbon input levels.
			Moist	0.69	±12%	
		Tropical	Dry	0.58	±61%	
			Moist/ Wet	0.48	±46%	
		Tropical montane[4]	n/a	0.64	±50%	
Land use (F_{LU})	Paddy rice	All	Dry and Moist/ Wet	1.10	±50%	Long-term (> 20 year) annual cropping of wetlands (paddy rice). Can include double-cropping with non-flooded crops. For paddy rice, tillage and input factors are not used.
Land use (F_{LU})	Perennial/ Tree Crop	All	Dry and Moist/ Wet	1.00	±50%	Long-term perennial tree crops such as fruit and nut trees, coffee and cacao.
Land use (F_{LU})	Set aside (< 20 yrs)	Temperate/ Boreal and Tropical	Dry	0.93	±11%	Represents temporary set aside of annually cropland (e.g., conservation reserves) or other idle cropland that has been revegetated with perennial grasses.
			Moist/ Wet	0.82	±17%	
		Tropical montane[4]	n/a	0.88	±50%	
Tillage (F_{MG})	Full	All	Dry and Moist/ Wet	1.00	NA	Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g., <30%) of the surface is covered by residues.
Tillage (F_{MG})	Reduced	Temperate/ Boreal	Dry	1.02	±6%	Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion). Normally leaves surface with >30% coverage by residues at planting.
			Moist	1.08	±5%	
		Tropical	Dry	1.09	±9%	
			Moist/ Wet	1.15	±8%	
		Tropical montane[4]	n/a	1.09	±50%	
Tillage (F_{MG})	No-till	Temperate/ Boreal	Dry	1.10	±5%	Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control.
			Moist	1.15	±4%	
		Tropical	Dry	1.17	±8%	
			Moist/ Wet	1.22	±7%	
		Tropical montane[4]	n/a	1.16	±50%	

TABLE 5.5 (CONTINUED)
RELATIVE STOCK CHANGE FACTORS (F_{LU}, F_{MG}, AND F_I) (OVER 20 YEARS) FOR DIFFERENT MANAGEMENT ACTIVITIES ON CROPLAND

Factor value type	Level	Temperature regime	Moisture regime[1]	IPCC defaults	Error[2,3]	Description
Input (F_I)	Low	Temperate/ Boreal	Dry	0.95	± 13%	Low residue return occurs when there is due to removal of residues (via collection or burning), frequent bare-fallowing, production of crops yielding low residues (e.g., vegetables, tobacco, cotton), no mineral fertilization or N-fixing crops.
			Moist	0.92	± 14%	
		Tropical	Dry	0.95	± 13%	
			Moist/ Wet	0.92	± 14%	
		Tropical montane[4]	n/a	0.94	± 50%	
Input (F_I)	Medium	All	Dry and Moist/ Wet	1.00	NA	Representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g., manure) is added. Also requires mineral fertilization or N-fixing crop in rotation.
Input (F_I)	High without manure	Temperate/ Boreal and Tropical	Dry	1.04	± 13%	Represents significantly greater crop residue inputs over medium C input cropping systems due to additional practices, such as production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, irrigation, frequent use of perennial grasses in annual crop rotations, but without manure applied (see row below).
			Moist/ Wet	1.11	± 10%	
		Tropical montane[4]	n/a	1.08	± 50%	
Input (F_I)	High – with manure	Temperate/ Boreal and Tropical	Dry	1.37	± 12%	Represents significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure.
			Moist/ Wet	1.44	± 13%	
		Tropical montane[4]	n/a	1.41	± 50%	

[1] Where data were sufficient, separate values were determined for temperate and tropical temperature regimes; and dry, moist, and wet moisture regimes. Temperate and tropical zones correspond to those defined in Chapter 3; wet moisture regime corresponds to the combined moist and wet zones in the tropics and moist zone in temperate regions.

[2] ± two standard deviations, expressed as a percent of the mean; where sufficient studies were not available for a statistical analysis to derive a default, uncertainty was assumed to be ± 50% based on expert opinion. NA denotes 'Not Applicable', where factor values constitute defined reference values, and the uncertainties are reflected in the reference C stocks and stock change factors for land use.

[3] This error range does not include potential systematic error due to small sample sizes that may not be representative of the true impact for all regions of the world.

[4] There were not enough studies to estimate stock change factors for mineral soils in the tropical montane climate region. As an approximation, the average stock change between the temperate and tropical regions was used to approximate the stock change for the tropical montane climate.

Note: See Annex 5A.1 for the estimation of default stock change factors for mineral soil C emissions/removals for Cropland.

Table A4. Biomass Accumulation Rates

TABLE 4.9
ABOVE-GROUND NET BIOMASS GROWTH IN NATURAL FORESTS

Domain	Ecological zone	Continent	Above-ground biomass growth (tonnes d.m. ha^{-1} yr^{-1})	Reference
Tropical	Tropical rain forest	Africa (≤20 y)	10	IPCC, 2003
		Africa (>20 y)	3.1 (2.3-3.8)	IPCC, 2003
		North America	0.9-18	Clark *et al.*, 2003 ; Hughes *et al.*, 1999
		South America (≤20 y)	11	Feldpausch *et al.*, 2004
		South America (>20 y)	3.1 (1.5-5.5)	Malhi *et al.*, 2004
		Asia (continental ≤20 y)	7.0 (3.0-11.0)	IPCC, 2003
		Asia (continental >20 y)	2.2 (1.3-3.0)	IPCC, 2003
		Asia (insular ≤20 y)	13	IPCC, 2003
		Asia (insular >20 y)	3.4	IPCC, 2003
	Tropical moist deciduous forest	Africa (≤20 y)	5	Harmand *et al.*, 2004
		Africa (>20 y)	1.3	IPCC, 2003
		North and South America (≤20 y)	7.0	IPCC, 2003
		North and South America (>20 y)	2.0	IPCC, 2003
		Asia (continental ≤20 y)	9.0	IPCC, 2003
		Asia (continental >20 y)	2.0	IPCC, 2003
		Asia (insular ≤20 y)	11	IPCC, 2003
		Asia (insular >20 y)	3.0	IPCC, 2003
	Tropical dry forest	Africa (≤20 y)	2.4 (2.3-2.5)	IPCC, 2003
		Africa (>20 y)	1.8 (0.6-3.0)	IPCC, 2003
		North and South America (≤20 y)	4.0	IPCC, 2003
		North and South America (>20 y)	1.0	IPCC, 2003
		Asia (continental ≤20 y)	6.0	IPCC, 2003
		Asia (continental >20 y)	1.5	IPCC, 2003
		Asia (insular ≤20 y)	7.0	IPCC, 2003
		Asia (insular >20 y)	2.0	IPCC, 2003
	Tropical shrubland	Africa (≤20 y)	0.2-0.7	Nygård *et al.*, 2004
		Africa (>20 y)	0.9 (0.2-1.6)	IPCC, 2003
		North and South America (≤20 y)	4.0	IPCC, 2003
		North and South America (>20 y)	1.0	IPCC, 2003
		Asia (continental ≤20 y)	5.0	IPCC, 2003
		Asia (continental >20 y)	1.3 (1.0-2.2)	IPCC, 2003
		Asia (insular ≤20 y)	2.0	IPCC, 2003
		Asia (insular >20 y)	1.0	IPCC, 2003
	Tropical mountain systems	Africa (≤20 y)	2.0-5.0	IPCC, 2003
		Africa (>20 y)	1.0-1.5	IPCC, 2003
		North and South America (≤20 y)	1.8-5.0	IPCC, 2003
		North and South America (>20 y)	0.4-1.4	IPCC, 2003
		Asia (continental ≤20 y)	1.0-5.0	IPCC, 2003
		Asia (continental >20 y)	0.5-1.0	IPCC, 2003
		Asia (insular ≤20 y)	3.0-12	IPCC, 2003
		Asia (insular >20 y)	1.0-3.0	IPCC, 2003
Subtropical	Subtropical humid forest	North and South America (≤20 y)	7.0	IPCC, 2003
		North and South America (>20 y)	2.0	IPCC, 2003
		Asia (continental ≤20 y)	9.0	IPCC, 2003
		Asia (continental >20 y)	2.0	IPCC, 2003
		Asia (insular ≤20 y)	11	IPCC, 2003
		Asia (insular >20 y)	3.0	IPCC, 2003
	Subtropical dry forest	Africa (≤20 y)	2.4 (2.3-2.5)	IPCC, 2003
		Africa (>20 y)	1.8 (0.6-3.0)	IPCC, 2003
		North and South America (≤20 y)	4.0	IPCC, 2003

TABLE 4.9 (CONTINUED)
ABOVE-GROUND NET BIOMASS GROWTH IN NATURAL FORESTS

Domain	Ecological zone	Continent	Above-ground biomass growth (tonnes d.m. ha^{-1} yr^{-1})	Reference
		North and South America (>20 y)	1.0	IPCC, 2003
		Asia (continental ≤20 y)	6.0	IPCC, 2003
		Asia (continental >20 y)	1.5	IPCC, 2003
		Asia (insular ≤20 y)	7.0	IPCC, 2003
		Asia (insular >20 y)	2.0	IPCC, 2003
	Subtropical steppe	Africa (≤20 y)	1.2 (0.8-1.5)	IPCC, 2003
		Africa (>20 y)	0.9 (0.2-1.6)	IPCC, 2003
		North and South America (≤20 y)	4.0	IPCC, 2003
		North and South America (>20 y)	1.0	IPCC, 2003
		Asia (continental ≤20 y)	5.0	IPCC, 2003
		Asia (continental >20 y)	1.3 (1.0-2.2)	IPCC, 2003
		Asia (insular ≤20 y)	2.0	IPCC, 2003
		Asia (insular >20 y)	1.0	IPCC, 2003
	Subtropical mountain systems	Africa (≤20 y)	2.0-5.0	IPCC, 2003
		Africa (>20 y)	1.0-1.5	IPCC, 2003
		North and South America (≤20 y)	1.8-5.0	IPCC, 2003
		North and South America (>20 y)	0.4-1.4	IPCC, 2003
		Asia (continental ≤20 y)	1.0-5.0	IPCC, 2003
		Asia (continental >20 y)	0.5-1.0	IPCC, 2003
		Asia (insular ≤20 y)	3.0-12	IPCC, 2003
		Asia (insular >20 y)	1.0-3.0	IPCC, 2003
Temperate	Temperate oceanic forest	Europe	2.3	
		North America	15 (1.2-105)	Hessl *et al*., 2004
		New Zealand	3.5 (3.2-3.8)	Coomes *et al*., 2002
		South America	2.4-8.9	Echevarria and Lara, 2004
	Temperate continental forest	Asia, Europe, North America (≤20 y)	4.0 (0.5-8.0)	IPCC, 2003
		Asia, Europe, North America (>20 y)	4.0 (0.5-7.5)	IPCC, 2003
	Temperate mountain systems	Asia, Europe, North America	3.0 (0.5-6.0)	IPCC, 2003
Boreal	Boreal coniferous forest	Asia, Europe, North America	0.1-2.1	Gower *et al*., 2001
	Boreal tundra woodland	Asia, Europe, North America	0.4 (0.2-0.5)	IPCC, 2003
	Boreal mountain systems	Asia, Europe, North America (≤20 y)	1.0-1.1	IPCC, 2003
		Asia, Europe, North America (>20 y)	1.1-1.5	IPCC, 2003

Appendix 2: Methane Conversion Factors

TABLE 10.17
MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS

System[a]		MCFs by average annual temperature (°C)																			Source and comments
		Cool					Temperate											Warm			
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Pasture/Range/Paddock		1.0%					1.5%											2.0%			Judgement of IPCC Expert Group in combination with Hashimoto and Steed (1994).
Daily spread		0.1%					0.5%											1.0%			Hashimoto and Steed (1993).
Solid storage		2.0%					4.0%											5.0%			Judgement of IPCC Expert Group in combination with Amon *et al.* (2001), which shows emissions of approximately 2% in winter and 4% in summer. Warm climate is based on judgement of IPCC Expert Group and Amon *et al.* (1998).
Dry lot		1.0%					1.5%											2.0%			Judgement of IPCC Expert Group in combination with Hashimoto and Steed (1994).
Liquid/Slurry	With natural crust cover	10%	11%	13%	14%	15%	17%	18%	20%	22%	24%	26%	29%	31%	34%	37%	41%	44%	48%	50%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001) and Sommer (2000). The estimated reduction due to the crust cover (40%) is an annual average value based on a limited data set and can be highly variable dependent on temperature, rainfall, and composition. When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to Formula 1.
	Without natural crust cover	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001). When slurry tanks are used as fed-batch storage/digesters, MCF should be calculated according to Formula 1.

TABLE 10.17 (CONTINUED)
MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS

System[a]		MCFs by average annual temperature (°C)																			Source and comments
		Cool					Temperate											Warm			
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Uncovered anaerobic lagoon		66%	68%	70%	71%	73%	74%	75%	76%	77%	77%	78%	78%	78%	79%	79%	79%	79%	80%	80%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001). Uncovered lagoon MCFs vary based on several factors, including temperature, retention time, and loss of volatile solids from the system (through removal of lagoon effluent and/or solids).
Pit storage below animal confinements	< 1 month	3%					3%											30%			Judgement of IPCC Expert Group in combination with Moller *et al.* (2004) and Zeeman (1994). Note that the ambient temperature, not the stable temperature is to be used for determining the climatic conditions. When pits used as fed-batch storage/digesters, MCF should be calculated according to Formula 1.
	> 1 month	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001). Note that the ambient temperature, not the stable temperature is to be used for determining the climatic conditions. When pits used as fed-batch storage/digesters, MCF should be calculated according to Formula 1.

TABLE 10.17 (CONTINUED)
MCF VALUES BY TEMPERATURE FOR MANURE MANAGEMENT SYSTEMS

System[a]		MCFs by average annual temperature (°C)																			Source and comments
		Cool					Temperate											Warm			
		≤ 10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	≥ 28	
Anaerobic digester		0-100%					0-100%											0-100%			Should be subdivided in different categories, considering amount of recovery of the biogas, flaring of the biogas and storage after digestion. Calculation with Formula 1.
Burned for fuel		10%					10%											10%			Judgement of IPCC Expert Group in combination with Safley *et al.* (1992).
Cattle and Swine deep bedding	< 1 month	3%					3%											30%			Judgement of IPCC Expert Group in combination with Moller *et al.* (2004). Expect emissions to be similar, and possibly greater, than pit storage, depending on organic content and moisture content.
Cattle and Swine deep bedding (cont.)	> 1 month	17%	19%	20%	22%	25%	27%	29%	32%	35%	39%	42%	46%	50%	55%	60%	65%	71%	78%	80%	Judgement of IPCC Expert Group in combination with Mangino *et al.* (2001).
Composting - In-vessel[b]		0.5%					0.5%											0.5%			Judgement of IPCC Expert Group and Amon *et al.* (1998). MCFs are less than half of solid storage. Not temperature dependant.
Composting - Static pile[b]		0.5%					0.5%											0.5%			Judgement of IPCC Expert Group and Amon *et al.* (1998). MCFs are less than half of solid storage. Not temperature dependant.
Composting - Intensive windrow[b]		0.5%					1.0%											1.5%			Judgement of IPCC Expert Group and Amon *et al.* (1998). MCFs are slightly less than solid storage. Less temperature dependant.
Composting – Passive windrow[b]		0.5%					1.0%											1.5%			Judgement of IPCC Expert Group and Amon *et al.* (1998). MCFs are slightly less than solid storage. Less temperature dependant.
Poultry manure with litter		1.5%					1.5%											1.5%			Judgement of IPCC Expert Group. MCFs are similar to sol id storage but with generally constant warm temperatures.
Poultry manure without litter		1.5%					1.5%											1.5%			Judgement of IPCC Expert Group. MCFs are similar to dry lot at a warm climate.
Aerobic treatment		0%					0%											0%			MCFs are near zero. Aerobic treatment can result in the accumulation of sludge which may be treated in other systems. Sludge requires removal and has large VS values. It is important to identify the next management process for the sludge and estimate the emissions from that management process if significant.

Formula 1 (Timeframe for inputs should reflect operating period of digester):

$MCF = [\{CH_4\ prod - CH_4\ used - CH_4\ flared + (MCF_{storage}/100 * B_o * VS_{storage} * 0.67)\}/(B_o * VS_{storage} * 0.67)] * 100$

Where:

CH_4 prod = methane production in digester , (kg CH_4) . Note: When a gas tight coverage of the storage for digested manure is used, the gas production of the storage should be included.
CH_4 used = amount of methane gas used for energy, (kg CH_4)
CH_4 flared = amount of methane flared, (kg CH_4)
$MCF_{storage}$ = MCF for CH_4 emitted during storage of digested manure (%)
$VS_{storage}$ = amount of VS excreted that goes to storage prior to digestion (kg VS)
When a gas tight storage is included: $MCF_{storage} = 0$; otherwise $MCF_{storage}$ = MCF value for liquid storage

[a] Definitions for manure management systems are provided in Table 10. 18.

[b] Composting is the biological oxidation of a solid waste including manure usually with bedding or another organic carbon source typically at thermophilic temperatures produced by microbial heat production.

Appendix 3: Emission Factors for Direct N_2O Emissions from Manure Management

TABLE 10.21
DEFAULT EMISSION FACTORS FOR DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

System	Definition		EF_3 [kg N_2O-N (kg Nitrogen excreted)$^{-1}$]	Uncertainty ranges of EF_3	Source[a]
Pasture/Range/ Paddock	The manure from pasture and range grazing animals is allowed to lie as is, and is not managed.		Direct and indirect N_2O emissions associated with the manure deposited on agricultural soils and pasture, range, paddock systems are treated in Chapter 11, Section 11.2, N_2O emissions from managed soils.		
Daily spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion. N_2O emissions during storage and treatment are assumed to be zero. N_2O emissions from land application are covered under the Agricultural Soils category.		0	Not applicable	Judgement by IPCC Expert Group (see Co-chairs, Editors and Experts; N_2O emissions from Manure Management).
Solid storage[b]	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.		0.005	Factor of 2	Judgement of IPCC Expert Group in combination with Amon *et al.* (2001), which shows emissions ranging from 0.0027 to 0.01 kg N_2O-N (kg N)$^{-1}$.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically. Dry lots are most typically found in dry climates but also are used in humid climates.		0.02	Factor of 2	Judgement of IPCC Expert Group in combination with Kulling (2003).
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water to facilitate handling and is stored in either tanks or earthen ponds.	With natural crust cover	0.005	Factor of 2	Judgement of IPCC Expert Group in combination with Sommer *et al.* (2000).
		Without natural crust cover	0	Not applicable	Judgement of IPCC Expert Group in combination with the following studies: Harper *et al.* (2000), Lague *et al.* (2004), Monteny *et al.* (2001), and Wagner-Riddle and Marinier (2003). Emissions are believed negligible based on the absence of oxidized forms of nitrogen entering systems in combination with low potential for nitrification and denitrification in the system.
Uncovered anaerobic lagoon	Anaerobic lagoons are designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilise fields.		0	Not applicable	Judgement of IPCC Expert Group in combination with the following studies: Harper *et al.* (2000), Lague *et al.* (2004), Monteny *et al.* (2001), and Wagner-Riddle and Marinier (2003). Emissions are believed negligible based on the absence of oxidized forms of nitrogen entering systems in combination with low potential for nitrification and denitrification in the system.
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility.		0.002	Factor of 2	Judgement of IPCC Expert Group in combination with the following studies: Amon *et al.* (2001), Kulling (2003), and Sneath *et al.* (1997).

TABLE 10.21 (CONTINUED)
DEFAULT EMISSION FACTORS FOR DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

System	Definition		EF_3 [kg N_2O-N (kg Nitrogen excreted)$^{-1}$]	Uncertainty ranges of EF_3	Source[a]
Anaerobic digester	Anaerobic digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CH_4 and CO_2, which is captured and flared or used as a fuel.		0	Not applicable	Judgement of IPCC Expert Group in combination with the following studies: Harper *et al.* (2000), Lague *et al.* (2004) Monteny *et al.* (2001), and Wagner-Riddle and Marinier (2003). Emissions are believed negligible based on the absence of oxidized forms of nitrogen entering systems in combination with low potential for nitrification and denitrification in the system.
Burned for fuel or as waste	The dung is excreted on fields. The sun dried dung cakes are burned for fuel.		The emissions associated with the burning of the dung are to be reported under the IPCC category 'Fuel Combustion' if the dung is used as fuel and under the IPCC category 'Waste Incineration' if the dung is burned without energy recovery.		
	Urine N deposited on pasture and paddock		Direct and indirect N_2O emissions associated with the urine deposited on agricultural soils and pasture, range, paddock systems are treated in Chapter 11, Section 11.2, N_2O emissions from managed soils.		
Cattle and swine deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.	No mixing	0.01	Factor of 2	Average value based on Sommer and Moller (2000), Sommer (2000), Amon *et al.* (1998), and Nicks *et al.* (2003).
		Active mixing	0.07	Factor of 2	Average value based on Nicks *et al.* (2003) and Moller *et al.* (2000). Some literature cites higher values to 20% for well maintained, active mixing, but those systems included treatment for ammonia which is not typical.
Composting - In-Vessel[c]	Composting, typically in an enclosed channel, with forced aeration and continuous mixing.		0.006	Factor of 2	Judgement of IPCC Expert Group. Expected to be similar to static piles.
Composting - Static Pile[c]	Composting in piles with forced aeration but no mixing.		0.006	Factor of 2	Hao *et al.* (2001).
Composting - Intensive Windrow[c]	Composting in windrows with regular turning for mixing and aeration.		0.1	Factor of 2	Judgement of IPCC Expert Group. Expected to be greater than passive windrows and intensive composting operations, as emissions are a function of the turning frequency.
Composting - Passive Windrow[c]	Composting in windrows with infrequent turning for mixing and aeration.		0.01	Factor of 2	Hao *et al.* (2001).
Poultry manure with litter	Similar to deep bedding systems. Typically used for all poultry breeder flocks and for the production of meat type chickens (broilers) and other fowl.		0.001	Factor of 2	Judgement of IPCC Expert Group based on the high loss of ammonia from these systems, which limits the availability of nitrogen for nitrification/denitrification.
Poultry manure without litter	May be similar to open pits in enclosed animal confinement facilities or may be designed and operated to dry the manure as it accumulates. The latter is known as a high-rise manure management system and is a form of passive windrow composting when designed and operated properly.		0.001	Factor of 2	Judgement of IPCC Expert Group based on the high loss of ammonia from these systems, which limits the availability of nitrogen for nitrification/denitrification.