THE 6th GREENHOUSE GAS INVENTORY SYSTEM TRAINING WORKSHOP

Session VII: Main Contents of 2006 IPCC Guideline - Vol.4 Agriculture, Forestry and Other Land Use (AFOLU)

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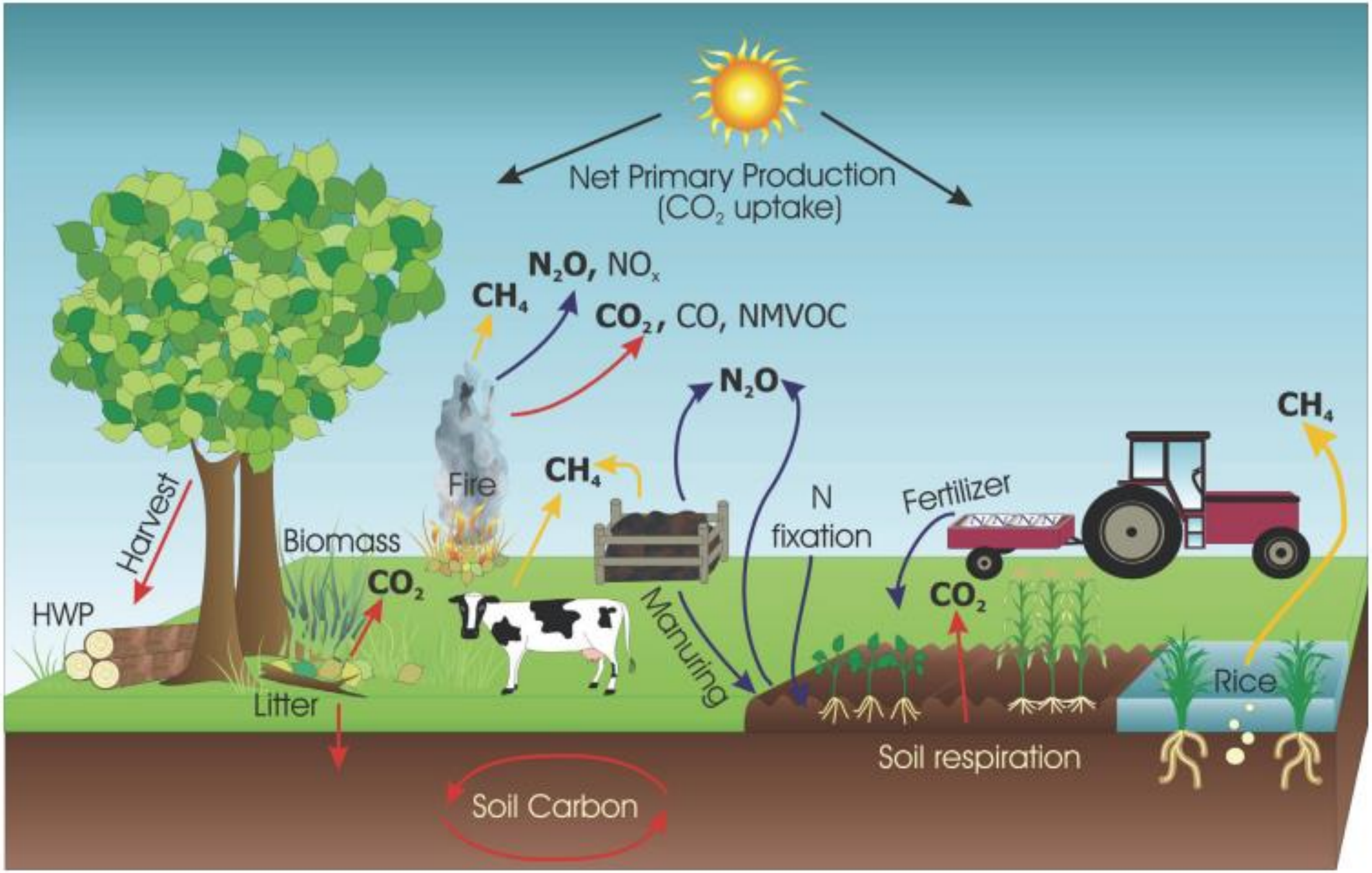
- The Agriculture sector
- The LULUCF sector

Agriculture, Forestry and Other Land Use (AFOLU) sector



Source: Figure 1.1, p1.6, Chapter 1, Volume 4, 2006GL

AFOLU in MPGs

- Reporting separately between the Agriculture and the LULUCF
  - Para 25, Annex 18/CMA.1: Each Party shall identify key categories.... below, including and excluding land use, land-use change and forestry (LULUCF) categories.
  - Para 50, Annex 18/CMA.1: Each Party shall report the following sectors: energy, industrial processes and product use, agriculture, LULUCF and waste

- The reporting categories are based on the CRT (CMA.3).
  - The way of separation of "A" and "FOLU" is shown here. Note that sector numbering is different between the 2006 IPCC Guidelines and the CRT.
    - The 2006 IPCC GL: whole AFOLU is category 3.
    - MPGs: the Agriculture is category 3, the LULUCF is category 4.
  - You may find some unclear or difficult to understand reporting.
    - The negotiation during CMA1 in 2024 was not perfect to develop the CRT tables for the AFOLU sector (ex. the 1996 IPCC GL's categories remains, no reporting cells for a certain sources of the 2013 wetlands supplements etc.)

The Agriculture Sector

Sub-categories in the AFOLU- Agriculture

- 3 Agriculture, Forestry and Other Land Use (AFOLU)
  - 3A Livestock
    - 3A1 Enteric Fermentation
    - 3A2 Manure Management
  - 3B Land
    - 3B1 Forestland
    - 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
    - 3C2 Liming
    - 3C3 Urea Application
    - 3C4 Direct N_2O emissions from managed soils
    - 3C5 Indirect N_2O emissions from managed soils
    - 3C6 Indirect N_2O emissions from manure management
    - 3C7 Rice Cultivations
    - 3C8 Other
  - 3D Other
    - 3D1 Harvested Wood Product
    - 3D2 Other

Category numbers are based on the 2006 IPCC GL

Sub-categories in the Agriculture sector

- Related to animal production:
  - Enteric Fermentation (3A1): CH_4 emissions from ruminants and non-ruminants
  - Manure Management (3A2): CH_4 emissions from manure managed under anaerobic conditions
  - Manure Management (3A2): N_2O emissions from manure when treated under different treatment systems

- Related to croplands:
  - Agricultural Soils (3C4-5): N_2O emissions from the surface of cropped soils due to anthropogenic N inputs; direct (primary) and indirect (secondary) emissions are considered.

- Use of lime and urea:
  - Lime and dolomite application (3C2): CO_2 emissions from decomposition
  - Urea application (3C3): CO_2 emissions from decomposition

Sub-categories in the Agriculture sector

- Related to cropping systems:
  - Rice cultivation (3C7): CH_4 emissions from the surface of soils kept under anaerobic conditions to cultivate rice

- Fire related emissions:
  - Prescribed burning of savannas (3C1): non-CO_2 gas emissions due to savanna biomass burning
  - Crop residue burning (3C1): non-CO_2 gas emissions due to dead biomass burning
  - Biomass burning on land (3C1) : non-CO_2 gas emissions due to biomass burning (wild fire, controlled burning)

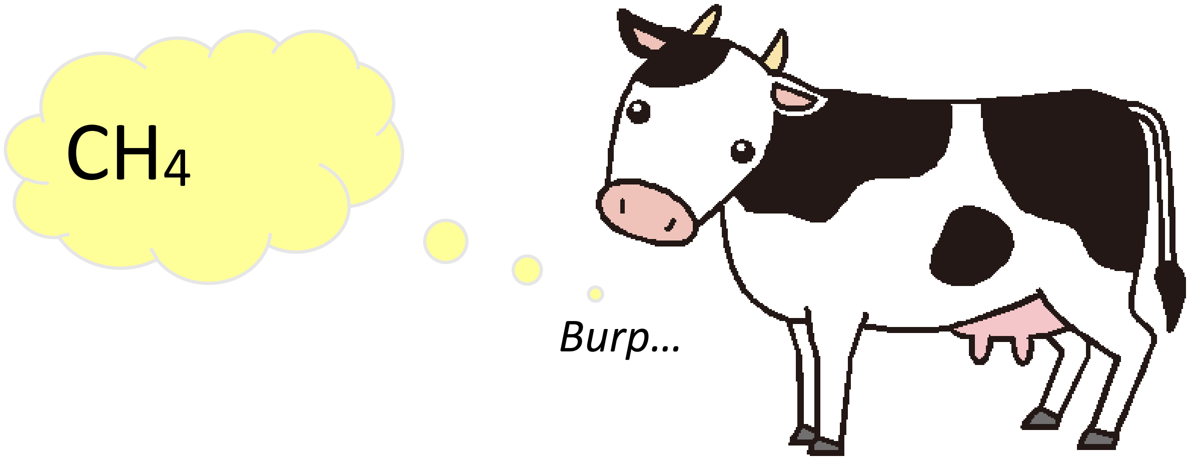
Summary table: Gases

Sector/source category	Numbering		CO_2	CH_4	N_2O	CO	NOx
	2006GL	CRT					
ENTERIC FERMENTATION	3A1	3.A		X			
MANURE MANAGEMENT	3A2	3.B.1-4		X	X		
BIOMASS BURNING	3C1	3.E, 3.F	X[1]	X	X	X[2]	X[2]
LIMING	3C2	3.G	X				
UREA APPLICATION	3C3	3.H	X				
DIRECT N_2O FROM SOIL	3C4	3.D.1			X		
INDIRECT N_2O FROM SOIL	3C5	3.D.2			X		
INDIRECT N_2O FROM MANURE MANAGEMENT	3C6	3.B.5			X		
RICE CULTIVATION	3C7	3.C		X			

[1] CO_2 emissions occur actually due to biomass burning. This can be calculated as a part of carbon stock changes of carbon pools under 3B land. In this case, CO_2 emissions are not reported here and not accounted for national total emission in order to avoid double counting.
[2] Precursors and indirect emissions with default EF. NMVOC and SO_2 are also mentioned in Vol.1 but not included in the sector table in the AFOLU. CO_2 converted from CO could be included in national inventories. (Section 7.2.1.5, Vol.1, 2006GL)

3A1 (3.A) Enteric Fermentation

Background



- Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the bloodstream.
- The amount of methane released depends on the population, age, weight and the quality and quantity of the feed consumed, etc.
- This sector covers emissions from cattle (daily, non-dairy), buffalo, goats, sheep, deer, camels, horses, mules and asses, swine, llamas, alpacas, etc.
- Chapter 10, Volume 4 of the 2006 IPCC Guidelines provide methodologies.

3A1 (3.A) Enteric Fermentation

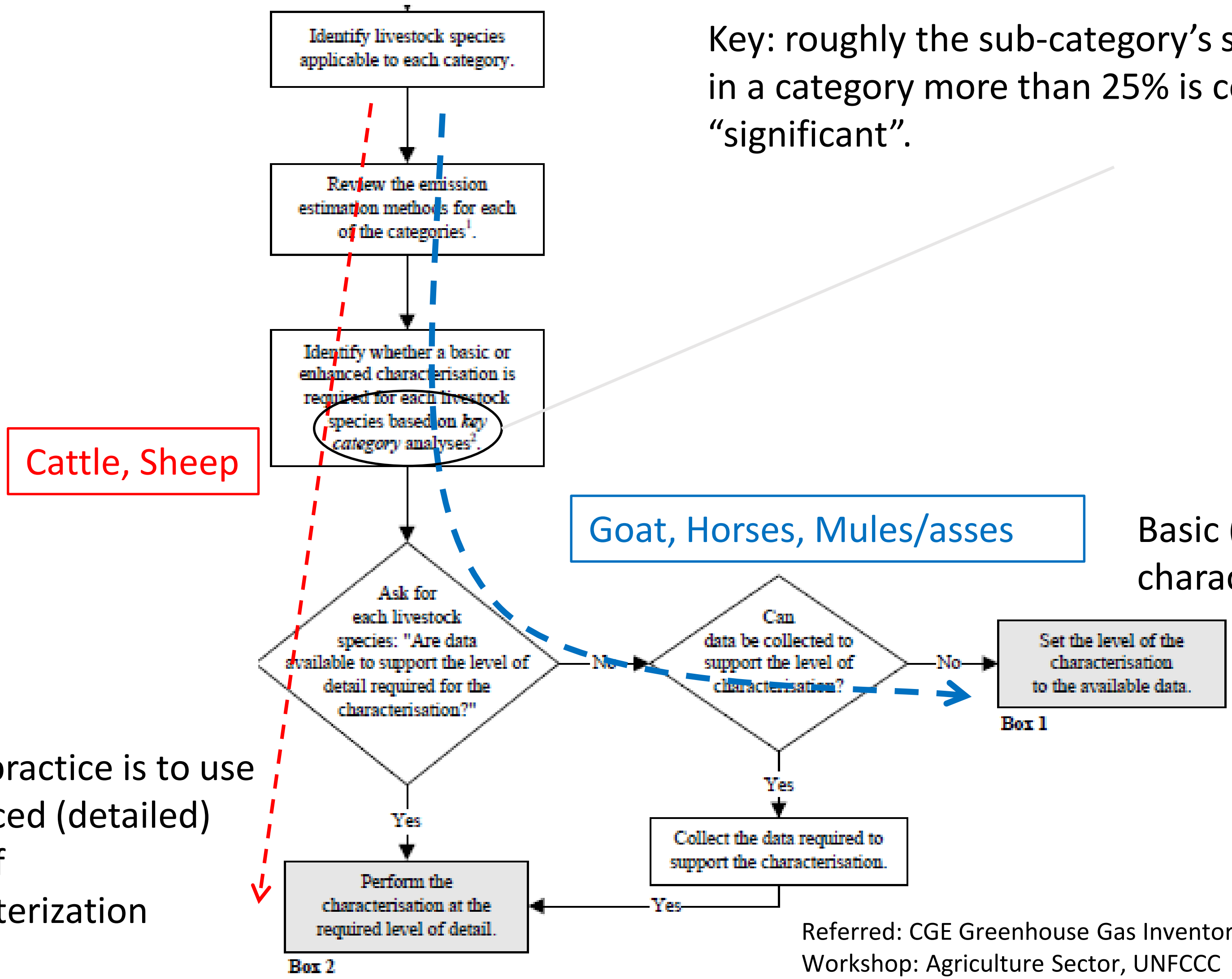
Step to estimate emissions

1. Identify livestock subcategories (for both 3A1 and 3A2)
   - Emission pathway slightly differ in each livestock species. (ex. ruminant vs. non-ruminant)
   - Different tier may apply (ex. Higher tier for dominant species)
2. Review the emission estimation method in each livestock level
   - Taking into account the decision trees and the relevant explanation in the IPCC GL about the suggested methods for enteric fermentation (Table 10.9, 2006GL-AFOLU)

Livestock	Suggested methods in 2006GL
Dairy Cow, Other Cattle	Tier.2/Tier.3
Buffalo, Sheep	Tier.1/Tier.2
Goats, Camels, Horses, Mules/Asses, Swine	Tier.1
Poultry	Not developed
Other	Tier.1

3A1 (3.A) Enteric Fermentation

Example of decision tree



Key: roughly the sub-category's share of emission in a category more than 25% is considered "significant".

Basic (single) level of characterization

Good practice is to use Enhanced (detailed) level of characterization

Referred: CGE Greenhouse Gas Inventory Hands-on Training Workshop: Agriculture Sector, UNFCCC

3A1 (3.A) Enteric Fermentation

Calculation methodologies

- Tier 1
  - Simply multiplying “animal population” and “EF (annual CH_4 emission per head)
  - Animal Population
    - Usually use statistical information. If possible, national data should be used. Alternatively, FAOSTAT data can be used.
    - Important note is that the number here means “annual average”. For instance, broiler chicken are typically grown 60 days > must be converted to 365days number.
  - Default EF
    - Provided by “livestock category” and “developed /developing countries)
- Tier 2
  - Also multiplying “animal population” and “EF (annual CH_4 emission per head)
  - But EF itself must be developed from other parameters which reflect the feed intake situation. Generally, the higher the feed intake, the higher the methane emission. Amount of diet may also affect methane production.
  - So for tier.2, animal population should also be divided into appropriate subgroup.

3A1 (3.A) Enteric Fermentation

The information affecting Tier 2 EF for enteric fermentation

Metabolic function	Applicability	Necessary data	Equation & Table
Maintenance (NE_m)	All in equilibrium	Live-weight of animal	Eq. 10.3, Table 10.4
Activity(NE_a)	All cattle	NE_m	Eq. 10.4, Table 10.5
	All sheep	Live-weight of animal	Eq. 10.5, Table 10.5
Growth (NE_g)	Growing cattle	Manure live body weight Average body weight of population Average daily weight gain	Eq. 10.6, Table 10.6
	Growing sheep	Live body weight at weaning Live body weight at 1-yr old or slaughter	Eq. 10.7, Table 10.6
Lactation (NE_l)	Female cattle in lactation	Amount of milk produced Fat content of milk	Eq. 10.8
	Female Sheep (milk production known)	Amount of milk production	Eq. 10.9
	Female Sheep (milk production known)	Weight gain of the lamb between birth and weaning	Eq. 10.10

3A1 (3.A) Enteric Fermentation

The parameters affecting Tier 2 EF for enteric fermentation

Metabolic function	Applicability	Necessary data	Equation & Table
Work (NE_{work})	Only for cattle used as worker	NE_m Number of hours of work/day	Eq. 10.11
Wool Production (NE_{wool})	Only for sheep	Annual wool production per sheep	Eq. 10.12
Pregnancy (NE_p)	All pregnancy	NE_m Live product produced by a female for sheep	Eq. 10.12, Table 10.7

parameter	Applicability	Necessary data	Equation & Table
Ratio of net energy available in diet for maintenance to digestible energy consumed	All for maintenance function	DE%	Eq. 10.15
Ratio of net energy available in diet for growth to digestible energy consumed	All for growth function	DE%	Eq. 10.16

3A1 (3.A) Enteric Fermentation

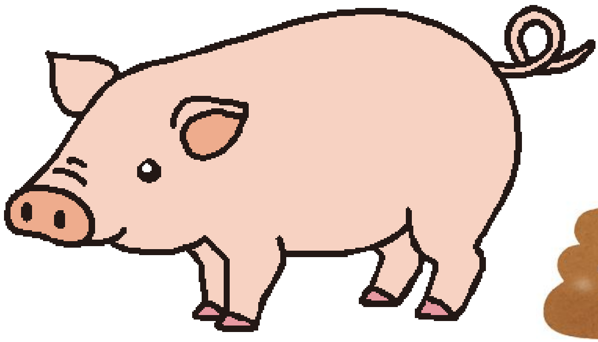
Quiz

- In this category, inventory compilers should prioritize
  1. Ruminant livestock
  2. Non-ruminant livestock

- There are many wild deer in my country. Inventory compilers
  1. Should collect data of this population and need to reflect it in the GHG inventory
  2. Can ignore this population and emissions.

3A2, 3C6 (3.B) Manure Management

Background



CH_4

N_2O

- When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it decomposes anaerobically and produce CH_4.
- The main factors affecting CH_4 emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically.
- Direct N_2O emissions occur by 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.
- Chapter 10, Volume 4 of the 2006 IPCC Guidelines provide methodologies.

3A2, 3C6 (3.B) Manure Management

Step to estimate CH_4 emissions

- Identify livestock subcategories: The same data developed in enteric fermentation can be used.
- Examine whether Tier.2 level estimation is possible or not based on availability of the CS parameters.
- From the decision tree:
  - if the source occurs but not key source

    Basic characterization – Tier 1 – Default EF
  - if the source occurs and key source: for the significant species (normally cattle, sheep, swine)

    Enhanced characterization – Tier 2 – CS EFs
  - for the non-significant species (normally, goats, camels, horses, asses, mules, poultry):

    Basic characterization – Tier 1 – Default EF
- If relevant country specific science is available, application of Tier.3 may also be considered.

3A2, 3C6 (3.B) Manure Management

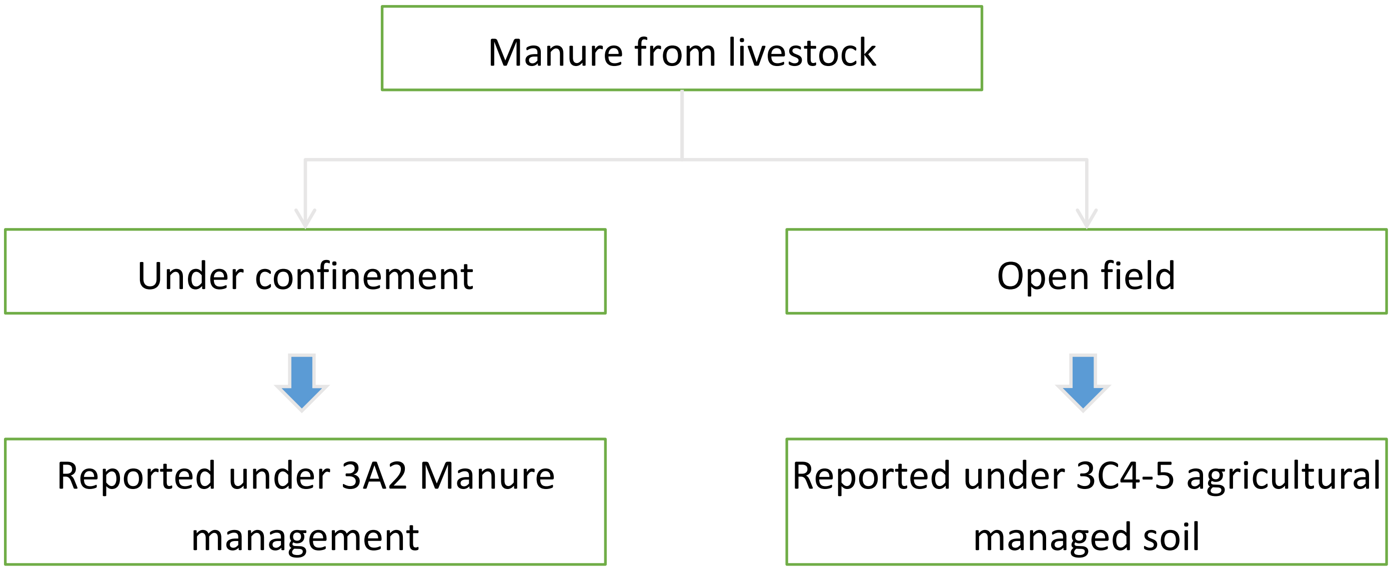
Calculation methodology for CH_4 emission

- Tier 1
  - Simply multiplying "animal population" and "EF (annual CH_4 emission per head)
  - Identify appropriate default EF: Default EFs for Tier.1 are provided by livestock species and by average annual temperature.
- Tier 2
  - Also multiplying "animal population" and "EF (annual CH_4 emission per head).
  - Activity data of animal population should be sub-divided into manure management system (MMS) type. The portion of manure management system type for each animal species is necessary.
  - Need to consider the three factors to establish the EFs under Tier.2.
    - Daily volatile solid (VS) excreted rate (calculated from "gross energy intake", "digestibility of the feed, and ash content of the manure).
    - Maximum amount of methane able to be produced from that manure (B_0).
    - Methane conversion factor (MCF) for each system by climate region.

3A2, 3C6 (3.B) Manure Management

Reporting of N_2O emissions from manure

- Special attention is necessary to the estimated category of N_2O emission from manure. A part of emissions are estimated under the agricultural managed soil categories.



- Necessary information
  - Amount of N excretion from animals: estimated by “population” and “N-excreted per head”.
  - How excreted N is managed: need to consider share of each Manure Management system (MS).

3A2, 3C6 (3.B) Manure Management

Calculation methodology for N_2O emission

- There are two type of N_2O emission: direct N_2O emission/ indirect N_2O emission:
  - Basically, the same activity data are applicable to both. EFs (EF_3-EF_5) are different.
  - For indirect N_2O emission, Tier.1 covers volatilization of N (fraction of emitted as gas), Tier.2 covers volatilization as well as leaching run off (fraction of runoff loss). Volatilization is almost unavoidable process, while leaching is able to be prevented by anthropogenic management practice.
- Tier 1 and Tier 2 uses the same equation
  - Multiplying “amount of N managed in each MS” and EF for each MS.
  - Activity data – required in addition to those necessary for the livestock characterization – are:
    - annual average N excretion per head/category/species
    - fraction of total annual excretion for each livestock species/category that is managed in a manure management system
  - Parties are also encouraged to disaggregate the activity data for each major climatic zone.

3A2, 3C6 (3.B) Manure Management

Quiz

- Both CH_4 emissions from enteric fermentation and CH_4 emissions from manure management to be influenced by temperature.
  1. Ture
  2. False

- Number of animal population can be commonly used for 3A1, 3A2, 3C6.
  1. Ture
  2. False

3C7 (3.C) Rice Cultivation

Background

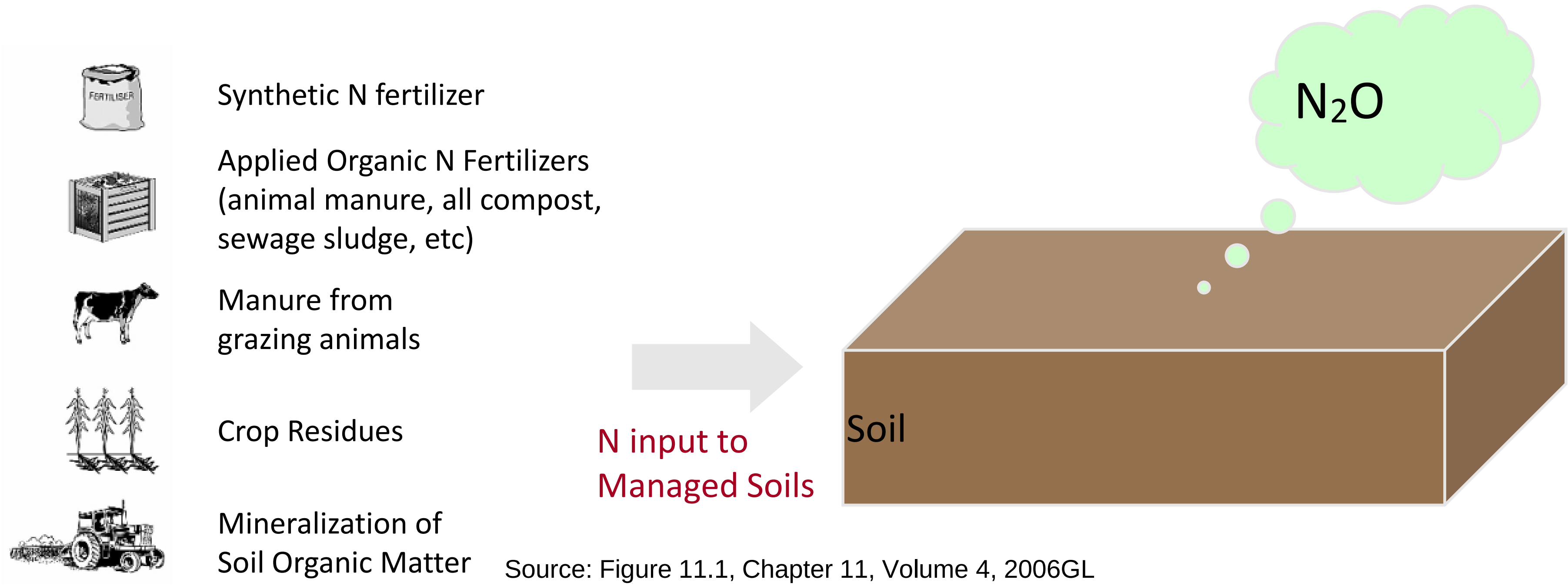
- Anaerobic decomposition of organic material in flooded rice fields produces methane.
- The annual amount of CH_4 emitted from rice cultivation depends on the area of rice fields, the number and duration of crops grown, water regimes before and during cultivation period, soil type, temperature, etc.
- Chapter 5, Volume 4 of the 2006 IPCC Guidelines provide methodologies.

3C7 (3.C) Rice Cultivation

Calculation methodologies

- Equation
  - multiplying "Area (annual harvested area of rice, ha)", "cultivation period of rice (days) " and "EF (daily CH_4 emission per area)
  - All terms are divided by conditions of rice cultivation influenced CH_4 emission such as
    - Ecosystem type: i.e. irrigated, rainfed, deep water rice production.
    - water regimes: continuously flooded, intermittently flooded
    - Type and amount of organic amendments: straw, green manure, compost, etc.
- EF
  - There is a standard default EF for Tier 1. This is adjusted by using scaling factors (parameters to adjust EF depending on water regime) and conversion factors (parameters to adjust EF depending on organic amendments).
  - Tier 2 can use CS EF from field measurements.
- AD
  - Primarily based on harvested area of rice field.
  - Should be broken down by conditions of rice cultivation.

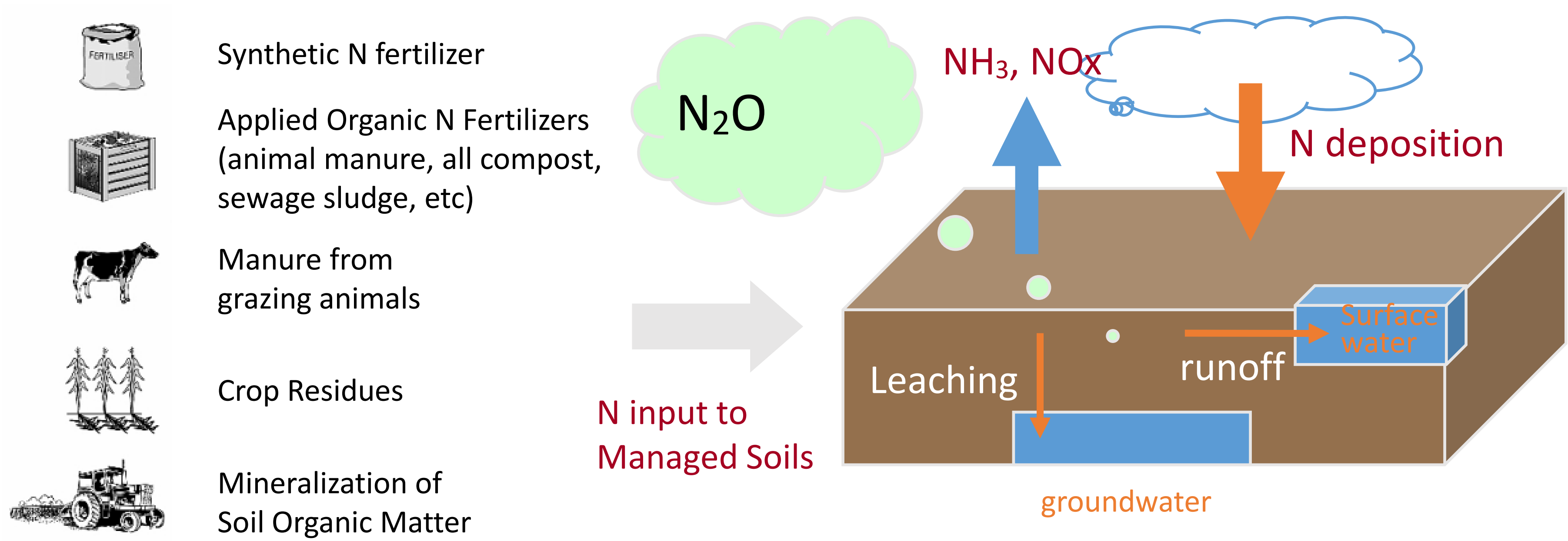
3C4 (3.D.1) Direct N_2O emissions from managed soils



Source: Figure 11.1, Chapter 11, Volume 4, 2006GL

- Nitrous oxide is produced naturally in soils through the processes of nitrification and denitrification. Nitrification is the aerobic microbial oxidation of ammonium to nitrate, and denitrification is the anaerobic microbial reduction of nitrate to nitrogen gas (N_2).
- This sector covers N_2O emissions from human-induced N additions to soils (e.g., synthetic or organic fertilizers, deposited manure, crop residues, sewage sludge), or of mineralization of N in soil organic matter following drainage/management of organic soils, or cultivation/land-use change on mineral soils.

N_2O emissions from managed soils



Source: Figure 11.1, Chapter 11, Volume 4, 2006GL

- Indirect N_2O emissions take place through two pathways.
- The first pathways is the volatilization of N as NH_3 and NOx, 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 second pathway is the leaching and runoff from land of N mainly in the NO_3^- form. The nitrification and denitrification processes transform some of the NH_4^+ and NO_3^- to N_2O.

N_2O emissions from managed soils

Calculation methodologies

- Equation
  - Basically, estimated by multiplying "AD", "EF (N_2O-N/unit) and 44/28 (converted from N_2 to N_2O).
  - Combination of terms for calculation are summarized below

Sources	AD	EF, direct N_2O emission	EF, indirect N_2O emission	
			volatilization	Leaching run-off
Application of synthetic fertilizers (F_{SN})	Amount of N input into managed soils	EF_1 *specific EF for flooded rice field	EF_4	EF_5
Application of organic N (such as animal manure, sewerage sludge) as fertilizers (F_{ON})				
Incorporation of crop residues including from N-fixing crops and from forages into soils (F_{CR})				
Soil N mineralization associated with loss of organic matter resulting from change of land use or management of mineral soils (F_{SOM})				
Urine and dung N deposited on pasture, range and paddock by grazing animals (F_{PRP})	Urine and dung N deposited	EF_3 (divided by major livestock and other)	EF_4	
Drainage/management of organic soil (F_{OS})	Area of drained / cultivated organic soils	EF_2 (by climate region and land use/management)		

N_2O emissions from managed soils

N sources and the correspondent EFs of direct N_2O emissions

- EF_1 is used for N inputs : F_{SN} , F_{ON}, F_{CR}, F_{SOM}
  - A single world-wide default EF is provided in the 2006GL
- EF_2 is used for drainage/management of organic soil: F_{OS}
  - Default EFs are provided by land use type (forest, cropland/grassland), and by climate zone.
  - Updated default EFs are available from the 2013 Wetlands Supplement.
- EF_3 is used for Urine and dung N deposit from grazing animal: F_{PRP}
  - Different default EFs are established for CPP (Cattle, Poultry and Pigs), and SO (Sheep and Other animals).
- EF_4 is used for Volatilization: F_{SN} , F_{ON} and F_{PRP}
  - Fraction of N volatilized, $Frac_{GASF}$ (for SN), $Frac_{GASM}$ (for ON and PRP) is multiplied to each F, to calculated amount of N volatilized
- EF_5 is used for Leaching/Runoff: F_{SN} , F_{ON} , F_{PRP} , F_{CR} and F_{SOM}
  - Fraction of N lost through leaching/runoff (applicable to all) is multiplied to total F, to calculated amount of N leaching/runoff.

N_2O emissions from managed soils

Collection of AD

- F_{SN}
  - Annual amount of N fertilizer applied is collected by annual N fertilizer consumption data from official country statistics or international data (IFIA, FAO)
  - In the 2006GL, tier.1 estimation does not have adjust for the amount of NH_3 and NOx volatilization. Tier.2 or 3 should be aware this correction.
- F_{ON}
  - Organic N fertilizer referred in the 2006GL include, 1) animal manure, 2) sewage N, 3) compost N, and 4)other organic amendments(brewery waste, guano ,etc)
  - Animal manure applied to soil is estimated by subtracting manure used for feed, fuel, construction from the total amount of manure N estimated in 3A2 manure management.(like top-down type estimation)
- F_{PRP}
  - The equation of estimating the amount of urine and dung N deposit is the exactly same one used in N_2O manure management. The amount manure treated in the management system of direct deposit on pasture, rangeland and paddock is used as the activity data here.
  - This data is calculated in 3A2 Manure Management. In the IPCC software, data used in 3A2 is reflected to 3C4 automatically.

N_2O emissions from managed soils

Collection of AD (continue)

- F_{CR}
  - Annual amount of N in crop residue is estimated from crop yield statistics and some factors: ratio of annual renew, residue to yield ratio and residue N contents. The effect of residue burning or removing from site are also taken into account. To convert from Yield fresh (usual statistical data) to dry fresh is implemented by using dry matter fraction of harvested crop.
  - Table 11.2 provides the default parameters of this estimation.
- F_{SOM}
  - Average annual loss of carbon in mineral soil estimated under 3B Land is the base data of this source. Using C:N ratio of soil to derive N input from carbon loss (ΔC).
  - N immobilization (estimated from carbon gain in mineral soil) is only considered under Tier.3 method.
- F_{OS}
  - Area of drained or cultivated organic soil is the activity data. This is the common AD used for N_2O and CO_2 (covered in 3B Land) (or CH_4 in the case the 2013 WLSL applied).

N_2O emissions from managed soils

This source of N_2O emission is relevant to both the Agriculture and the LULUCF

Sources	Note for Agriculture sector	Note for LULUCF sector
Application of synthetic fertilizers (F_{SN}) Application of organic N (such as animal manure, sewerage sludge) as fertilizers (F_{ON})	Mostly applied in agricultural land use.	Covers only application to non-agricultural land uses. Allowed to use "IE" in the LULUCF and can report all N_2O under the Agriculture sector.
Incorporation of crop residues including from N-fixing crops and from forages into soils (F_{CR})	N in crop residue become source of N_2O emissions	C in crop residue can contribute to increase carbon stock in agriculture soils
Soil N mineralization associated with loss of organic matter resulting from change of land use or management of mineral soils (F_{SOM})	Covers remaining land (agriculture management) N mineralized is estimated by using carbon stock loss calculated in the LULUCF sector.	Covers converted land (land use change) and non-agricultural land uses.
Urine and dung N deposited on pasture, range and paddock by grazing animals (F_{PRP})	N in urine and dung become source of N_2O emissions	C in urine and dung may contribute carbon input in grazing land,
Drainage/management of organic soil (F_{OS})	Covers N_2O emissions. Only drained area needed.	Covers CO_2 (and CH_4) emissions. Total and drained area needed.

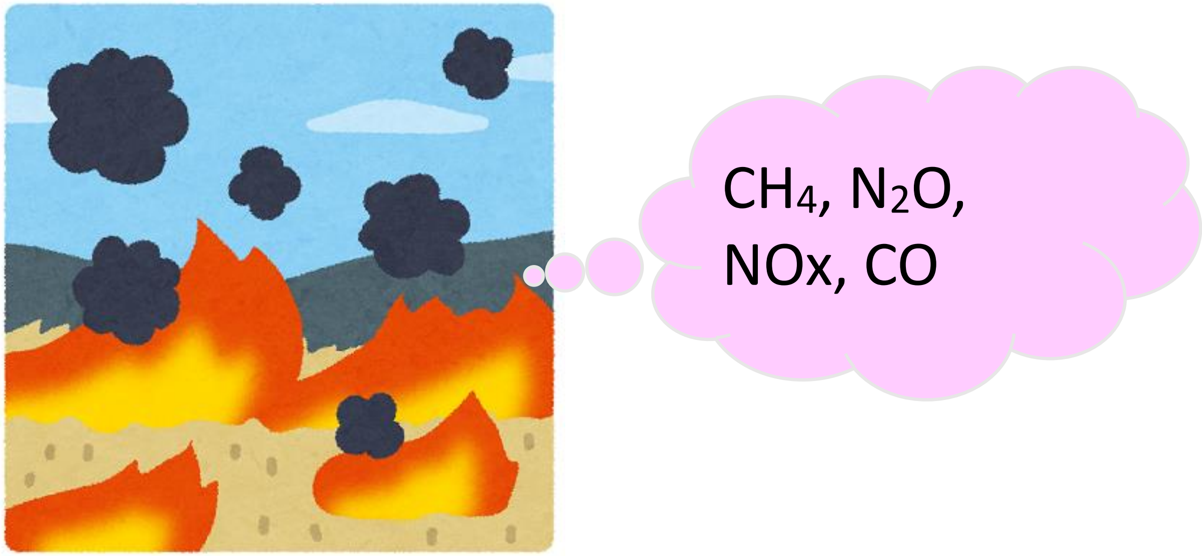
N_2O emissions from managed soils

Quiz

- What to you think the most priority issue for estimating this source in your country.
  1. To construct top-down Nitrogen flow from animals, crops and other.
  2. To develop country-specific EF.
  3. To collect N application data from national data such as agriculture survey, selling data, production data.
  4. To implement Tier 1 estimation using FAOSTAT data.

3C1 (3.E, 3.F) GHG emissions from biomass burning

Background



- Burning of agricultural residues in the fields is a common practice in the developing countries. Biomass burning is used primarily to clear remaining straw and stubble after harvest and to prepare the field for the next cropping cycle.
- In this process, CH_4, N_2O, CO and NOx are emitted.
- Chapter 2, Volume 4 of the 2006 IPCC Guidelines provide methodologies.

3C1 (3.E, 3.F) GHG emissions from biomass burning

<u>Methodological issues</u>

- Biomass burning is an integrated category including the following emission sources which used to be categorized under the Agriculture sector and the LULUCF sector.
  - Prescribed Burning on Savannas: Agriculture – Not relevant to cool/ temperate country (this comes from the 1996 IPCC GL and so suggested to be deleted from CRT during the UNFCCC negotiation, but it could not do so)
  - Field burning on crop residue: Agriculture
  - Controlled fire implemented in forest land, grassland: LULUCF
  - Wildfire occurred mainly in forest land, grassland: LULUCF
  - On-site, off-site burning of biomass generated by land use change: LULUCF
- Fire basically affect biomass pool. In the higher tier for forest land or grassland fire, carbon pools such as dead organic matter may also be considered.
- All fire occurred in managed land should be estimated, regardless its origin is human-induced or wildfire.
- Woody vegetation is encouraged to use higher tier.
- Mass balance should be paid attention to the amount of agricultural residue. A part of residue may be used as fuel, fertilization, and etc,.

3C1 (3.E, 3.F) GHG emissions from biomass burning

Calculation methodologies

- Relating to land use
  - GHG = (area burnt: A)

    * (mass of fuel available for combustion per area: M_B)

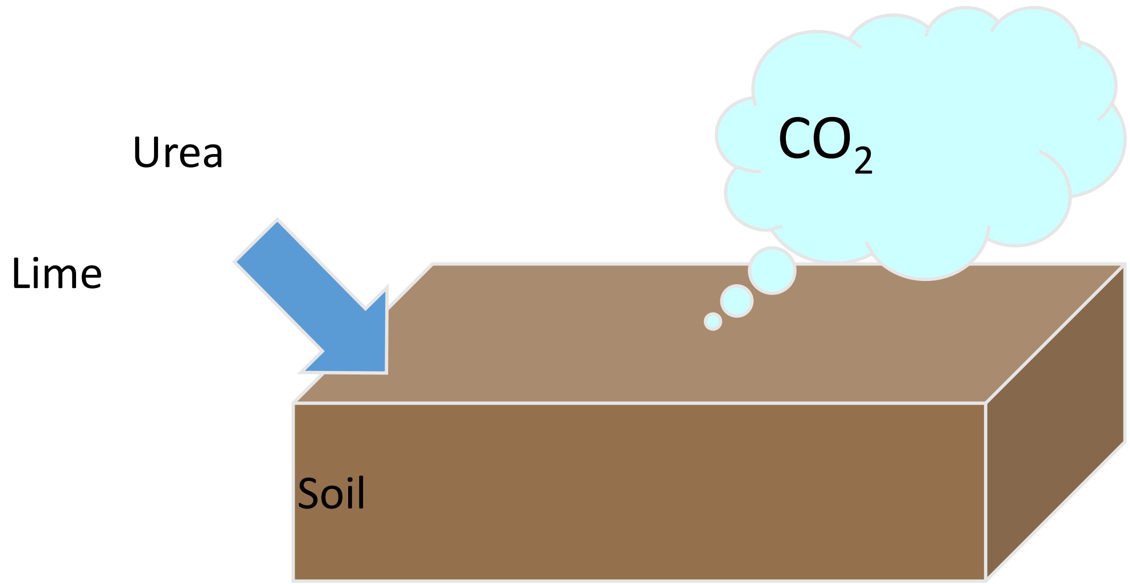
    * (combustion factor (ratio of burnt): C_f)

    * (emission factor: G_{ef})
  - Parameters of MB, Cf, G_{ef} are available from Tables 2.4, 2.5, 2.6 in chapter 2

- Relating to agricultural residue burning
  - Usually “actual biomass burnt” value are directly used instead of $A*M_B$
  - Actual biomass burnt is often estimated from “crop yield (statistical data)” with “yield to residue ratio”, and “ratio of burnt in residue”

3C2 (3.G) Liming, 3C3 (3.H) Urea application

<u>Background</u>



- Application of limestone, dolomite or urea into soil is often a part of fertilization or amendment of soil property in agricultural practice.
- Due to the reaction in soil, CO_2 is generated and emitted to atmosphere.
  - ✓ Limestone: $CaCO_3 + H_2O \rightarrow CaO + CO_2$
  - ✓ Dolomite : $CaMg(CO_3)_2 \rightarrow CaO + MgO + CO_2$
  - ✓ Urea : $CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2$
- Chapter 11, Volume 4 of the 2006 IPCC Guidelines provide methodologies.

3C2 (3.G) Liming, 3C3 (3.H) Urea application

Calculation methodologies

- Equation
  - multiplying “Amount of application” and “EF”.
- EF
  - EFs are established from atomic weight basis.
  - Under Tier 2, all carbon in limestone, dolomite and urea may not be emitted in the year of application depending on site-level characteristics. If sufficient data is available to adjust EF, country can use CS-EF (I have never see such case so far).

The LULUCF Sector

Sub-categories in the AFOLU

- 3 Agriculture, Forestry and Other Land Use (AFOLU)
  - 3A Livestock
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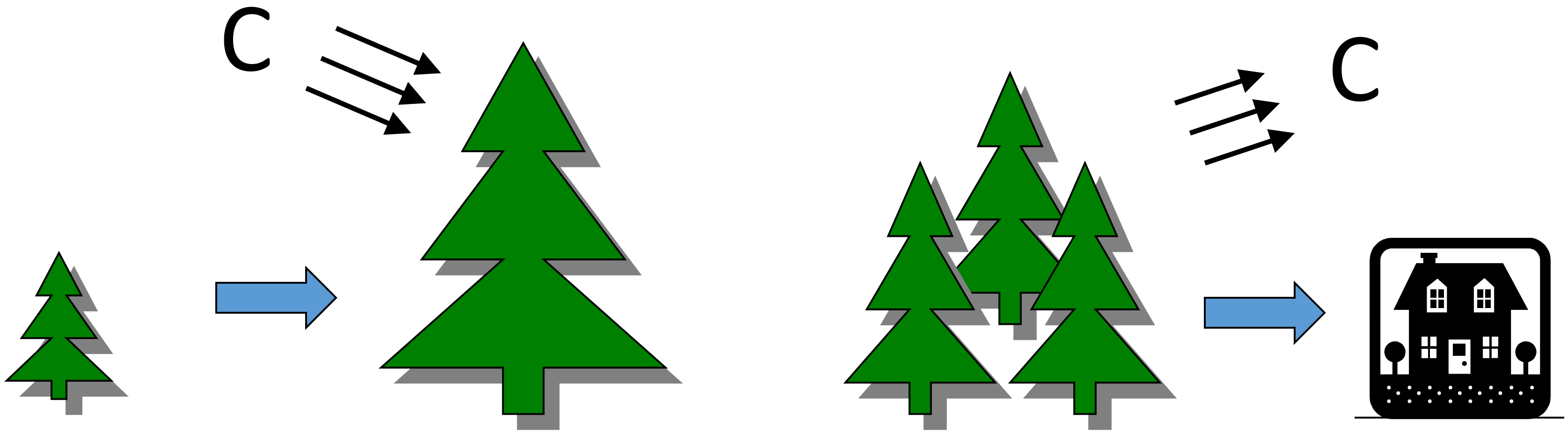
    - 3B4 Wetlands
    - 3B5 Settlements
    - 3B6 Other land
  - 3C Aggregate sources and non-CO_2 emissions sources on land
    - 3C1 GHG emissions from biomass burning
    - 3C2 Liming
    - 3C3 Urea Application
    - 3C4 Direct N_2O emissions from managed soils
    - 3C5 Indirect N_2O emissions from managed soils
    - 3C6 Indirect N_2O emissions from manure management
    - 3C7 Rice Cultivations
    - 3C8 Other
  - 3D Other
    - 3D1 Harvested Wood Product
    - 3D2 Other

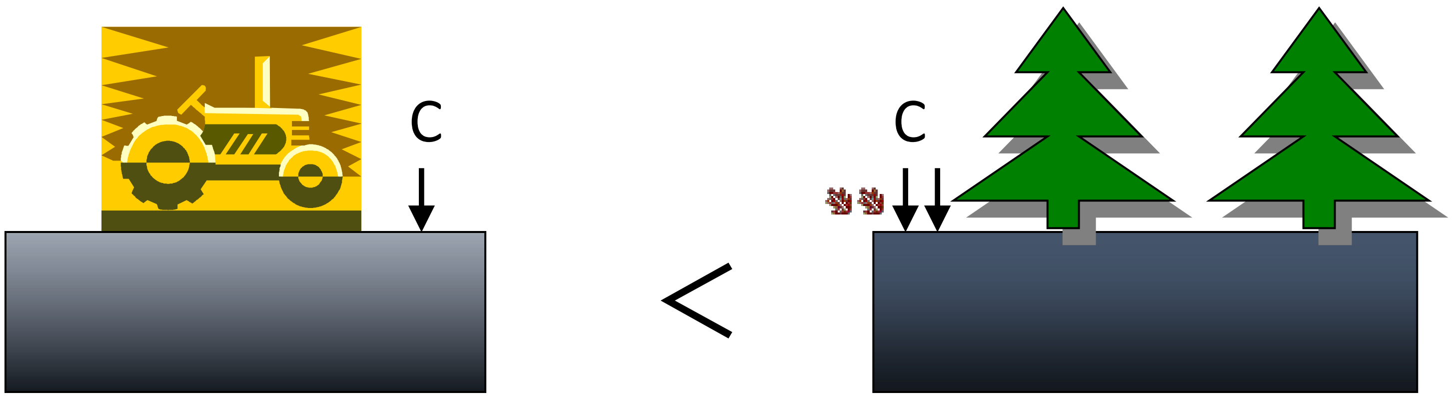
Category numbers are based on the 2006 IPCC GL

Emissions and Removals on Land

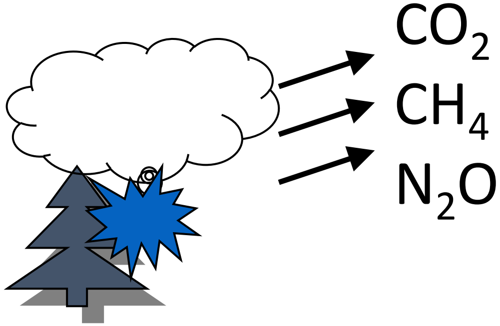


- Growth of vegetation / biomass
  → sequestration of carbon from atmosphere : REMOVALS
- Loss of vegetation / biomass
  → release of carbon to atmosphere : EMISSIONS

Emissions and Removals in LULUCF



- Land use and Management have impact to carbon in soil as well.



- Several other source events (ex. Fire, insect damage)

Anthropogenic and managed land

- UNFCCC reporting of GHG only treat “anthropogenic” emissions and removals.
  - For instance, GHGs from volcanic eruption are not covered and not necessary to report under the GHG inventory.
  - Land ecosystem carbons change due to both natural and anthropogenic effects. It is also difficult to distinguish human induced effect and natural/indirect human effect.
  - The concept of “managed land proxy” is used to distinguish anthropogenic and non anthropogenic emissions and removals.
    - For the AFOLU Sector, anthropogenic greenhouse gas emissions and removals by sinks are defined as all those occurring on ‘managed land’.
    - Managed land is land where human interventions and practices have been applied to perform production, ecological or social functions.

Land use classification

- To identify land use status for all land territory, all land is classified under the six broad land use categories
  - Forest land
  - Cropland
  - Grassland
  - Wetlands
  - Settlements
  - Other land

- A party can use its own definitions to classify land use categories.
- Avoid double counting and omission of land as much as possible.

Land use classification: definition

- Forest land
  - Forest land includes all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, sub-divided into managed and unmanaged.
  - It also includes systems with vegetation that currently fall below, but *in situ* could reach the threshold values used by a country to define the forest land category.
- Cropland
  - Cropland includes cropped land (arable and tillage land), and agro-forestry systems where vegetation structure falls below the threshold used for the forest land category, consistent with the selection of national definitions.
  - Generally, all cropland is considered as managed.
- Grassland
  - Grassland includes rangelands and pasture land that is not considered as cropland. It also includes systems with woody vegetation and other non-grass vegetation such as herbs and brushes that fall below the threshold values used in the Forest Land category.
  - The category also includes all grassland from wild lands to recreational areas, as well as agricultural and silvi-pastural systems consistent with national definitions.
  - Grassland may have both managed grassland and unmanaged grassland.

Land use classification: definition

- Wetlands
  - Wetlands includes area of peat extraction and land that is covered or saturated by water for all or part of the year and that does not fall into Forest land, Cropland, Grassland or Settlements categories. It includes reservoirs, as a managed sub-division, and natural rivers and lakes, as unmanaged sub-divisions.
- Settlements
  - Settlements include all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent national definitions.
- Other land
  - Other land includes bare soil, rock, ice, and all land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.
- Additional notes
  - Hierarchy of land classification may be used. Ex. settlements defined as the land not fall into forest land, cropland, grassland, and wetlands.
  - For implementing estimations, detailed sub-land use categories are often necessary. Ex. orchard and annual crop under cropland

Land use classification: "Remaining land" and "Converted land"

- Each land use category is further divided into two subcategories, so called "remaining land" and "converted land" based on the status and recent history of the land use.

- Remaining land
  - Remaining land is land that begin and end an inventory period in the same land use. In other word, land that is not subject to land use change during past 20 years is classified as remaining land.

- Converted land
  - Converted land is land converted from one land use category to another land use within the past 20 years (as a default). Land should be reported in a conversion category for 20 years, and then moved to a "remaining category", unless a further change occurs.

Calculation of Carbon Stock Changes

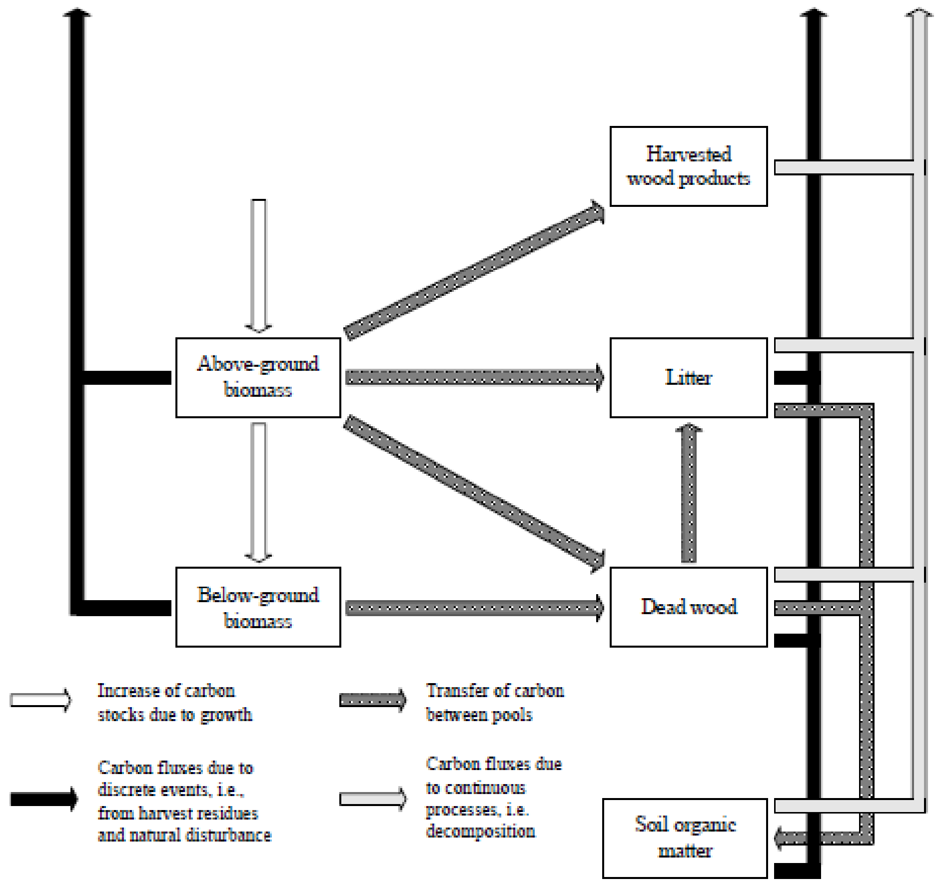
- Based on five carbon-pools
  - Above ground biomass
  - Below ground biomass
  - Dead wood
  - Litter
  - Soil organic matter (mineral soil and organic soil)
  - Harvested wood product (HWP) (usually relevant to forest land only)

- There are different transition period of carbon stock change
  - The separation of remaining lands and converted land is based on the default assumption that soli organic matter reaches a new equilibrium under new land use category after 20 years from the point of land use change (LUC).
  - Note that the activity data of carbon stock change is not always land use change area within past 20 years. The followings are examples of the default year(s) of conversion to use as activity data for estimation.
    - 1 year: Loss of Living biomass stock and dead organic matter due to LUC
    - 10 years: Loss of soil carbon for land use conversion to reservoir (non-mandatory category)
    - 20 years: Carbon stock changes of mineral soil due to LUC, gain of dead organic matter for land converted to forest land

Carbon stock among pools

- Loss of carbon in a certain carbon pool often be a gain in other carbon pool.

Figure 2.1 Generalized carbon cycle of terrestrial AFOLU ecosystems showing the flows of carbon into and out of the system as well as between the five C pools within the system.



Source: Figure 2.1, p2.8, Chapter 2, Volume 4, 2006GL

Methodologies of land in the 2006 IPCC GL (Tier 1)

Pools and GHG to be reported at the Tier 1 level. Non-CO_2 gas emissions are reported under the LULUCF sector.

TIER.1		Land use												
Carbon pool, GHG		Forest land		Cropland		Grassland		Wetlands			Settlements		Other land	
		FF	LF	CC	LC	GG	LG	WW(PE)	LW(PE)	LW(F)	SS	LS	OO	LO
LB	AGB	M	M	M[1]	M[2,3]		M[2,3]		M[3]	M[3]		M[3]		M[3]
	BGB		M		M[2,3]		M[2,3]		M[3]	M[3]		M[3]		M[3]
DOM	DW		M		M[3]		M[3]					M[3]		M[3]
	LT		M		M[3]		M[3]					M[3]		M[3]
Soil	Mineral		M	M	M	M	M					M		M[3]
	Organic	M	M	M	M	M	M	M				M		
HWP		M (may be assumed 0 if net C stock change is judged insignificant)												
N_2O	Fertilization[4]	M	M	M	M	M	M				M	M		
	Mineralization[4]		M		M		M					M		M
	Drainage[5]	M	M	M	M	M	M	M			M	M		
	Burning[5]	M	M	M	M	M	M	M	M		M	M		M
CH_4	Burning	M	M	M	M	M	M	M	M		M	M		M

M Mandatory
Grey Not applicable
Blank Not mandatory (including to report no change)
[1] To be reported only for perennial crops
[2] Net C stock gain in biomass pool for annual crops
[3] Only if any C stock is reported in the previous land category. In such a case C stock is to be reported as instantaneous oxidized in the year of conversion
[4] Direct emissions and indirect emissions
[5] Only direct emissions

Source: Prepared by the UNFCCC materials for GHG inventory review for Annex I countries

Methodologies of land in the 2006 IPCC GL (Tier 2)

Pools and GHG to be reported at the Tier 2 level. Non-CO_2 gas emissions are reported under the LULUCF sector.

TIER.2		Land use												
Carbon pool, GHG		Forest land		Cropland		Grassland		Wetlands			Settlements		Other land	
		FF	LF	CC	LC	GG	LG	WW(PE)	LW(PE)	LW(F)	SS	LS	OO	LO
LB	AGB	M	M	M[1]	M[2]	M	M[2]		M	M	M	M[3]		M
	BGB	M	M	M[1]	M[2]	M	M[2]		M	M	M	M[3]		M
DOM	DW	M	M	M	M	M	M		M		M	M[3]		M
	LT	M	M	M	M	M	M		M		M	M[3]		M
Soil	Mineral	M	M	M	M	M	M				M	M		M
	Organic	M	M	M	M	M	M	M			M	M		
HWP		M (may be assumed 0 if net C stock change is judged insignificant)												
N_2O	Fertilization[4]	M	M	M	M	M	M				M	M		
	Mineralization[4]	M	M	M	M	M	M				M	M		M
	Drainage[5]	M	M	M	M	M	M	M			M	M		
	Burning[5]	M	M	M	M	M	M	M	M		M	M		M
CH_4	Burning	M	M	M	M	M	M	M	M		M	M		M

M Mandatory
Grey Not applicable
Blank Not mandatory (including to report no change)

[1] To be reported only for perennial crops
[2] Net C stock gain in biomass pool for annual crops
[3] Only if any C stock is reported in the previous land category. In such a case C stock is to be reported as instantaneous oxidized in the year of conversion
[4] Direct emissions and indirect emissions
[5] Only direct emissions

Source: Prepared by the UNFCCC materials for GHG inventory review for Annex I countries

Methodologies: Three generic equations

- In the LULUCF, CO_2 emissions and/or removals from carbon pools are calculated based on carbon stock change (ΔC) multiplying the conversion factor to CO_2: 44/12. There are three generic equations to estimate carbon stock changes or emissions.
- Gain- Loss type
  - Carbon stock change is calculated by carbon gain (removal) minus carbon loss (emission).
  - Applies to living biomass estimation.

  $\Delta C = C\ gain - C\ loss$
- Stock-Different type
  - Carbon stock change is calculated by comparing with carbon stock of two points overtime.
  - Applies to living biomass, mineral soil estimations and others

  $\Delta C = (C2 - C1) / T$
- AD x EF type
  - Emissions are usually calculated by activity data (AD) multiplying emission factor (EF) similar to other sectors. Applies to non-carbon pool types of emission sources, organic soil estimation/

  Emissions = EF x AD

Biomass: feature

- Biomass is a dominant carbon pool for forest land and other perennial woody vegetation (such as orchard, urban trees).
- Both Gain-loss estimation and stock difference estimations are applicable.
- Basically, estimation of carbon stock changes is implemented to perennial woody biomass.
- For annual herbaceous vegetation, there are some extent of biomass, but annual change is considered as zero, based on the assumption that annual uptake of carbon is released in the same year. For the land use change estimation, the biomass amount on land is used for loss estimation or gain estimation. Thus, setting an averaged biomass carbon amount of on annual herbaceous vegetation on land.

Biomass: Gain-Loss method

Gain estimation

- The basic method: Estimation of gain is multiplying “area where removals occur” and “removals ratio per unit of area”
- Stratification: Removals ratio depends on tree type/forest type, climate condition, vegetation type and other factors. Default parameters are sometimes prepared with categorized taking into above. Thus, usually appropriate levels of stratification is conducted.
- The following equation is used in gain estimation method

C gain (t-C/yr) = Area (ha) * Annual Increment Rate (t-d.m./ha/yr) * Carbon Fraction (t-C/t-d.m.)

(Annual Increment Rate) = (Above ground biomass increment) * {1 + (Root to shoot ratio)}

(Above ground biomass increment) = (Annual net increment volume)* (Basic wood density) *(Biomass Expansion Factor for Increment)

Note: in the 2006 IPCC GL, D*BEF is integrated into BCEF

Biomass: Gain-Loss method

Loss estimation

- Three loss components:
  - Commercial felling (wood removals)
    - Source of activity data is annual extracted volume of roundwood which is usually stem volume-based information. The total amount of carbon loss is estimated to expand from stem to whole tree multiplying BCEFR, (or BEFR and wood density) and Carbon fraction.
    - A part of wood is not extract from harvesting site and left in forest. This left biomass decays and transfers to DOM and/or soil pools or atmosphere.
    - Harvesting data is not so stratified into sub-category such as by tree species in most countries. As $BCEF_R$ has the sub-categories of broadleaf and coniferous, these two forest types are may be considered at a minimum.
  - Fuelwood gathering
    - Activity data is annual volume of fuel wood gathered. Total amount of carbon loss is estimated by the same method used for wood removals
  - Other losses (disturbance)
    - Emissions from disturbance are estimated based on biomass stock lost by disturbances including fire, insect, windstorm etc.
    - The amount of lost volume is obtained from areas affected by disturbances multiplied by biomass stock per area, and fraction of biomass left to decay in the forest.

Biomass: Stock Difference method

- The Stock-Difference Method requires biomass carbon stock inventories for a given land area, at two points in time. Annual biomass change is the difference between the biomass stock at time t_2 and time t_1, divided by the number of years between the inventories.

  $\Delta C = (C_2 - C_1) / (t_2 - t_1)$

- This method requires country-specific volume inventory data (of forest for instance) and suitable for a country adopting Tier.2 or Tier 3 approaches but may not be suitable for countries using a Tier 1 approach due to limitations of data.
- It is usually said that result of Stock-Difference Method is more accurate than that of Gain-Loss Method.
- Each carbon stock is estimated by multiplying merchantable volume (V, m^3/ha), basic wood density (D, t-d.m./m^3), biomass expansion factor for conversion of merchantable volume to aboveground tree biomass (BEF_S, dimensionless), root to shoot ratio (R) and carbon fraction (CF, t-C/t-d.m.).

Biomass: Method applied for CSC due to LUC

- The emissions and removals (from ΔC) calculation associated with land conversion includes three main components,
  1. loss of biomass existed in previous land use during land conversion ($\Delta C_{CONVERSION}$),
  2. gains of biomass occurred in new land use(ΔC_G), and
  3. loss of biomass occurred in new land use (ΔC_L) (this is only considered under higher tier.)

$$\Delta C = \Delta C_{CONVERSION} + \Delta C_G - \Delta C_L$$

$$\Delta C_{CONVERSION} = \Sigma_i\{(B_{AFTER,\,i} - B_{BEFORE,\,i}) * A_{CONVERSION,\,i}\} *CF$$

$B_{AFTER,\,i}$: biomass stocks on land type i immediately after the conversion

$B_{BEFORE,\,i}$: biomass stocks on land type i immediately before the conversion

$A_{CONVERSION,\,i}$: area of land use i converted to another land-use category in a certain year

- Timing of emissions and removals:
  - Biomass loss is considered cleared and calculate as immediate emission to atmosphere (carbon loss) in the year of conversion. If, biomass amount in previous land use is insignificant, this is generally negligible.
  - If a country considers stock changes in Harvested Wood Product pool, carbon transfer to HWP is occurred and is not considered as immediate emission.
  - Carbon gains occurs until reaching a steady state of biomass stock.
- Place of carbon gain occur:
  - After conversion, biomass accumulation is estimated in conversions to forest land (afforestation) for many years, to grassland (, including abandoned managed land) for several years , to annual cropland for a year and to perennial wood crop in cropland (fruit, industrial crop such as oil palm, rubber) for some years.

Dead Organic Matter

- Dead wood and litter (dead organic matter: DOM) are increased through litterfall, mortality, and biomass turnover and decreased by decay.
- Usually, DOM pool is dominant /relevant only in forest land.
- For remaining land categories, Tier. 1 suggests that their stocks are not changing overtime and so report zero change.
- Tier 2 is only applicable when DOM stock data is available at least two point of time (stock-difference), or when inflow and outflow data relating to DOM pool is available (gain-loss). In reality, most of Annex I countries which report DOM carbon stock change are using Tier 3 (model for soil).
- For converted land categories, DOM loss is estimated in deforestation (land converted from forest land) and DOM gain is estimated in afforestation (land converted to forest land). Default litter stock data is available in the 2006GL, but no default dead wood stock data provided in the 2006GL.
- In other word, Tier.1 estimation is possible if LUC areas of deforestation and afforestation are available.

Soils

- For mineral soils, the estimation method is based on stock difference method.
- When land use or land management has changed, soil carbon stock changes and it takes time to reach a new steady state. The default time period is 20 years for this transition.
  - In Tier.1 and Tier.2 for mineral soils, the estimation method is based on stock difference method comparing with soil organic carbon (SOC) amount in two point of time. Annual change is calculated by the difference of SOC divided by the transition period
  - The state of SOC is estimated by referenced stock (SOC_{ref} = native state) and carbon factors relevant to land use (F_{LU}), management (tillage frequency) (F_{MG}) and input (F_I).

EQUATION 2.25

ANNUAL CHANGE IN ORGANIC CARBON STOCKS IN MINERAL SOILS

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$$SOC = \sum_{c,s,i} \left(SOC_{REF_{c,s,i}} \bullet F_{LU_{c,s,i}} \bullet F_{MG_{c,s,i}} \bullet F_{I_{c,s,i}} \bullet A_{c,s,i} \right)$$

(Note: T is used in place of D in this equation if T is ≥ 20 years, see note below)

Soils

- Mineral soils
  - Activity data of this estimation is not annual change area but total changed area during the time period such as past 20 years.
  - Default depth for estimation is up to 30cm. The 2006GL mentions it possible to use other depth.

- Organic soils
  - Cultivated or drained area is included in their estimation.
  - Emission is estimated based on area of cultivated or drained multiplying EF appropriate to their climate region.
  - Non-cultivated /non-drained organic soil area is also necessary for land use classification.

Harvested Wood Product

Background

- The carbon absorbed by trees remains in harvested wood until products made from this wood decay or are burned.
- Harvested wood products (HWP) contribute to carbon sequestration and the mitigation of climate change through increased use and end-of-lifecycle use of long-lived wood products, the use of by-products (wood waste) for energy, and the substitution of wood from sustainably managed forests for non-wood material in the construction sector.
- The IPCC guidelines provide methodology to estimate carbon stock changes of HWP in chapter 12, volume 4.
- MPGs for HWP
  - Can use any approach, but estimated result using production approach shall be included in the GHG inventory.

Harvested Wood Product

Multiple choice of HWP estimation

- **Whether do CSC of HWP consider or not**
  - If not considered, carbon is estimated as instantaneous oxidation at the time of harvesting and removed from forest. (Instantaneous Oxidation)
    - Suitable for countries having small HWP contribution or want to avoid difficult calculation.
- **How to consider internationally traded HWP**
  - Include domestically produced and domestically consumed wood only. Exclude imported and exported wood. (SCAD approach: a part of production approach)
    - Suitable for assessing HWP contribution without any influence from trading.
  - Include domestically produced wood both domestically consumed and exported.
    - Suitable for promoting domestic wood production.
  - Include all wood production within country both domestically produced and imported.
    - Suitable for promoting mitigation of wood usage.
- **How to calculate transferred carbon from forest to HWP**
  - Consider as loss of forest carbon and gain of HWP carbon (pool-based consideration)
    - Suitable for separate calculation of forest and HWP contribution
  - Do not consider any carbon stock change due to no real transfer to atmosphere (flux-based consideration)
    - Similar consideration of fuel combustion. 化石燃料の燃焼と同じような計算で、排出を考えたい場合向け。

CO_2 emissions from biomass use for energy and waste

CO_2 emissions from biomass use for energy and waste are not counted national total GHG emissions (so called "biogenic"). The reason is as follows:

- Biogenic CO_2 emissions from annual crop biomass and perennial woody biomass are to be accounted in the AFOLU (Land) sector as a part of national total emissions.
- For annual crops, the increase in biomass stocks in a single year is assumed equal to the biomass losses from harvest and mortality in that same year - thus there is no net accumulation of biomass carbon stocks, and Carbon losses (CO_2 emissions) by combustion is to be included in the loss process of this balanced estimation.
- For perennial woody biomass including forests, the default assumption for harvesting trees assumes an instantaneous oxidation of the carbon at the time of harvesting, so the CO_2 emissions occurring from the combustion is already accounted for at the time of harvesting under the AFOLU (Land) sector.

Inter Annual Variability

- Land use relating emissions from the AFOLU sector sometimes have larger inter annual variability than other sector.
- This is because significant emission is generated by such as large deforestation (ex. creation of dam), large events of disturbance (fire) and/or extra-ordinary high temperature (cause more decomposition when using models).
- The amount of such events are not stable year by year, although there is a general probability of occurrence in time series. (ex, recent years have more deforestation than before due to economic growth and settlements expansion in forest area).
- This is more relating to accounting than estimation.
- In the 2006GL, general concept is to estimate “real “ emissions in each year. Averaging the estimation result is not encouraged to eliminate inter annual variability, but averaging input data taking into account its environmental condition is allowed to do. (See page 2.11 “Multi-year averaging”, Chapter 2, Volume 1, 2006GL)

Quiz

- A Party can apply different tiers for different carbon pools in the same land use.
  1. True
  2. False

- In the estimation of converted land, the land use change area used for living biomass calculation and that used for soil calculation always should be the same.
  1. True
  2. False

- Rubber plantation should be classified
  1. Under forest land because it meets forest definition.
  2. Under cropland because it produce agricultural production.
  3. Depending on national definition

- A country classified rice field under wetlands category in the LULUCF sector because these area are mostly under the scope of Ramsar Convention. This approach is
  1. Acceptable .
  2. Unacceptable.

Exercise

Please download Excel file.