Agriculture Forestry and Other Land Use (AFOLU)

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Outline

• Introduction
• IPCC Guidelines for Agriculture and land-use
• AFOLU
  – 3A. Livestock
  – 3B. Land
  – 3C. Aggregate sources and non-CO₂ emissions on land
• Cross-cutting issues
• Exercise
Introduction

- Land use change and management have a significant influence on the greenhouse gas concentrations in the atmosphere.
- Processes accounting for emissions and removals in the biosphere are: photosynthesis, respiration, decomposition, nitrification/de-nitrification, enteric fermentation, and combustion that are driven by the biological activity and physical processes.
- AFOLU represents 20-24% of net anthropogenic emissions, equivalent to 10-12GtCO₂ eq/yr (AR5 – based on the 2010 GHG inventory datasets).
- A significant proportion of GHG emissions/removals in the AFOLU sector come from developing countries.
Terrestrial sources/sinks of GHGs

- Methanogenesis
- Photosynthesis
- Oxidation
- Methanogenesis
- Nitrification & denitrification
Evolution of IPCC Guidance on agriculture and land-use

**1996 IPCC GLs**
- Agriculture and Land Use and Change and Forestry (LUCF) separate sectors
- Only the most important activities resulting in GHG emissions/removals
- Implicit assumption about estimating emissions and removals only over lands subject to human intervention
- Only accounted for above-ground biomass and soil C pools

**GPG & GPG-LULUCF**
- Agriculture and Land Use, Land-use Change and Forestry (LULUCF) separate sectors
- Provides *good practice* and uncertainty management guidance
- Now includes all land use emissions/removals split into six land-use categories from all pools
- Explicit Use of *managed* land as a proxy for anthropogenic emissions/removals

**2006 IPCC Guidelines**
- Agriculture and Land Use and Change and Forestry (LUCF) combined into a single sector Agriculture, Forestry and Other Land Use (AFOLU)
- Same approach as GPG-LULUCF
- Retained use of *managed* land
- Inclusion and consolidation of several previously optional categories
- Refinement of methods and improved defaults
Evolution of IPCC Guidance on Agriculture and LUCF/LULUCF
Agriculture Forestry and Other Land Use (AFOLU)

3A. Livestock
3B. Land
3C. Aggregate Sources and Non-CO$_2$ Emissions on Land
3A. LIVESTOCK
3A. Livestock emissions

3A. Livestock

3.A.1 Enteric Fermentation

3.A.2 Manure Management

- CH₄
- N₂O
- CH₄
Three methodological Tiers

Tier 3:
Higher order methods
detailed modeling and/or inventory measurement systems
data at a greater resolution
lower uncertainties than the previous two methods

Tier 2:
A more accurate approach
country or region-specific values for the general defaults
more disaggregated activity data
relatively smaller uncertainties

Tier 1:
Simple first order approach
default values of the parameters from the IPCC guidelines
spatially coarse default data based on globally available data
large uncertainties & simplifying assumptions
Livestock population and feed characterization

- It could be necessary to use different methodological tiers for different source categories for the same livestock types.
- It is a good practice to identify the appropriate method for estimating emissions for each source category, and then base the livestock information (characterisation) on the most detailed requirements identified for each livestock species.

Basic Characterization
- Used for Tier 1 methods
- Livestock species and categories
- Annual population
- Dairy cows and milk production

Enhanced Characterization
- Used for Tier 2/3 methods
- Definitions for livestock subcategories
- Livestock population by subcategory
- Feed intake estimates

Characterization may undergo iteration based on the needs assessed during the emissions estimation process.
Steps to livestock characterization

**Identify livestock species that contribute to more than one source category**
- Typically: cattle, buffalo, sheep, goats, swine, horses, camels, mules/asses, and poultry

**Review the emission estimation method (tier) for each relevant source category (EF & MM)**
- Existing inventory or Tier 1 methods

**Identify the most detailed characterisation required for each livestock species**
- Basic characterization sufficient for Tier 1 methods for both EF & MM but “Enhanced” characterization is required if Tier 2 is required for either of them.
Decision tree for livestock population characterisation
<table>
<thead>
<tr>
<th>Main categories</th>
<th>Subcategories</th>
</tr>
</thead>
</table>
| Mature Dairy Cow or Mature Dairy Buffalo            | • High-producing cows that have calved at least once and are used principally for milk production  
|                                                     | • Low-producing cows that have calved at least once and are used principally for milk production |
| Other Mature Cattle or Mature Non-dairy Buffalo      | Females:  
|                                                     | • Cows used to produce offspring for meat  
|                                                     | • Cows used for more than one production purpose: milk, meat, draft  
|                                                     | Males:  
|                                                     | • Bulls used principally for breeding purposes  
|                                                     | • Bullocks used principally for draft power |
| Growing Cattle or Growing Buffalo                    | • Calves pre-weaning  
|                                                     | • Replacement dairy heifers  
|                                                     | • Growing / fattening cattle or buffalo post-weaning  
|                                                     | • Feedlot-fed cattle on diets containing ≥ 90% concentrates |
| Mature Ewes                                          | • Breeding ewes for production of offspring and wool production  
|                                                     | • Milking ewes where commercial milk production is the primary purpose |
| Other Mature Sheep (>1 year)                         | • No further sub-categorisation recommended |
| Growing Lambs                                        | • Intact males  
|                                                     | • Castrates  
|                                                     | • Females |
Tier 2: Enhanced characterisation for livestock populations

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

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

- Tier 2 emissions estimates require feed intakes for a representative animal in each subcategory.
- Feed intake is typically measured in terms of gross energy (e.g., mega joules (MJ) per day) or dry matter (e.g., kilograms (kg) per day).
  - Dry matter is the amount of feed consumed (kg) after it has been corrected for the water content in the complete diet.
- For all estimates of feed intake, *good practice* is to:
  - Collect data to describe the animal’s typical diet and performance in each subcategory;
  - Estimate feed intake from the animal performance and diet data for each subcategory.
**Gross energy**

- Animal performance and diet data are used to estimate feed intake, which is the amount of Gross Energy (MJ/day) an animal needs for maintenance and for activities such as growth, lactation, and pregnancy.

- Total net energy requirement for animal performance and feed digestibility data are used to estimate the Gross Energy (GE).

- The feed intake in kg day\(^{-1}\) should be calculated by converting from GE in energy units to dry matter intake (DMI), by dividing GE by the energy density of the feed.
Net Energy for animal performance

- Net Energy for work (NEwork)
- Net Energy for lactation (NEI)
- Net Energy for maintenance (NEm)
- Net Energy for activity (NEa)
- Net Energy for pregnancy (NEp)
- Net Energy for growth (NEg)
- Net Energy for wool (NEwool)
Decision Tree for livestock categories

1. To be repeated for each livestock species and gas

2. Significant livestock species account for 25-30% or more of emissions from the source category
IPCC Methodological Guidance: Calculating emissions for Enteric Fermentation and Manure Management
Enteric Fermentation: Tier 1 method

\[\text{Emissions} = EF(T) \cdot \left(\frac{N(T)}{10^6}\right)\]

Where:
- Emissions = methane emissions from Enteric Fermentation, Gg CH\(_4\) yr\(^{-1}\)
- EF(T) = emission factor for the defined livestock population, kg CH\(_4\) head\(^{-1}\) yr\(^{-1}\)
- N(T) = the number of head of livestock species / category T in the country
- T = species/category of livestock

\[\text{Total CH}_4\text{Enteric} = \sum_i E_i\]

Where:
- Total CH\(_4\)Enteric = total methane emissions from Enteric Fermentation, Gg CH\(_4\) yr\(^{-1}\)
- Ei = is the emissions for the ith livestock categories and subcategories
Enteric Fermentation: Tier 2 Method

\[
EF = \left( \frac{GE \cdot \left( \frac{Y_m}{100} \right)}{55.65} \right) \cdot 365
\]

Where:
EF = emission factor, kg Gg CH\(_4\) yr\(^{-1}\)
GE = gross energy intake, MJ head\(^{-1}\) day\(^{-1}\)
Ym = methane conversion factor, per cent of gross energy in feed converted to methane. The factor 55.65 (MJ/kg CH\(_4\)) is the energy content of methane
Choice of emission factors

• Tier 1 method requires default EFs for the livestock subcategories according to the basic characterization scheme.

• Tier 2 methods require country-specific EFs estimated for each animal category based on the gross energy intake estimated using the detailed data on animal feed and performance and methane conversion factor for the category.
Choice of activity data

• Tier 1 method requires collection of livestock population data according to basic characterization.
• Tier 2 method requires animal population data according to single livestock enhanced characterisation depending upon the most disaggregated data requirements between enteric fermentation and manure management categories.
Methodological tiers- Enteric Fermentation

Tier 1.
- Enteric fermentation is not a key source category
- Enhanced characterization data not available.
- Approximate enteric emissions are derived by extrapolation from main livestock categories

Tier 2
- Uses country-specific data on gross energy intake and methane conversion factors for specific livestock categories.
- Should be used if enteric fermentation is a key source category for the animal category that represents a large portion of the country’s total emissions.

Tier 3
- Sophisticated models that consider diet composition in detail, concentration of products rising from ruminant fermentation, seasonal variation in animal population or feed quality and availability, and possible mitigation strategies.
Enteric fermentation: Calculation steps for all Tiers

**Step 1:** Divide the livestock population subgroups and characterize each subgroup preferably using annual averages (production cycles and seasonal influences on population numbers).

**Step 2:** Estimate emission factors for each subgroup in kg CH$_4$/animal/yr.

**Step 3:** Multiply the subgroup emission factors by the subgroup populations to estimate subgroup emission, and sum across the subgroups to estimate total emission.
Manure Management (CH$_4$)

• CH$_4$ is produced during the storage and treatment of manure, and from manure deposited on pasture.

• Most favourable conditions for CH$_4$ production are when large numbers of animals are managed in a confined area (e.g., dairy farms, beef feedlots, and swine and poultry farms), and where manure is disposed of in liquid-based systems.

• The main factors affecting CH$_4$ emissions are the amount of manure produced and the portion of the manure that decomposes anaerobically that are influenced by storage conditions (liquid/solid), retention times and temperature.
Manure Management (CH$_4$) (2)

\[
CH_4^{\text{Manure}} = \sum_{(T)} \left( \frac{EF(T) \cdot N(T)}{10^6} \right)
\]

Where:

$CH_4^{\text{Manure}}$ = CH$_4$ emissions from manure management, for a defined population, Gg CH$_4$ yr$^{-1}$

$EF(T)$ = emission factor for the defined livestock population, kg CH$_4$ head$^{-1}$ yr$^{-1}$

$N(T)$ = the number of head of livestock species/category $T$ in the country

$T$ = species/category of livestock
Choice of emission factors

• Tier 1
  – Default methane emission factors for manure management by livestock category or subcategory are used.
  – Default emission factors represent the range in manure volatile solids content and in manure management practices used in each region.

• Tier 2
  – The Tier 2 method relies on two primary types of inputs that affect the calculation of methane emission factors from manure: manure characteristics and MMS characteristics.
Choice of emission factors (2)

• **Manure characteristics** includes:
  - the amount of volatile solids (VS) produced in the manure
    • VS can be estimated based on feed intake and digestibility, which are the variables also used to develop the Tier 2 enteric fermentation emission factors.
  - the maximum amount of methane able to be produced from that manure (Bo)
    • Bo varies by animal species and feed regimen and is a theoretical methane yield based on the amount of VS in the manure.

• **Manure management system characteristics** includes:
  - the types of systems used to manage manure and a system-specific methane conversion factor (MCF) that reflects the portion of Bo that is achieved.
    • Regional assessments of MMS are used to estimate the portion of the manure handled with each.
Choice of emission factors (3)

\[
EF(T) = \left( VS(T) \cdot 365 \right) \cdot \left[ Bo(T) \cdot 0.67 \text{ kg} / \text{m}^3 \cdot \sum_{S,k} \frac{MCF_{S,k}}{100} \cdot MS(T,S,k) \right]
\]

Where:
EF(T) = annual \( \text{CH}_4 \) emission factor for livestock category \( T \), kg \( \text{CH}_4 \) animal\(^{-1} \) yr\(^{-1} \)

\( VS(T) \) = 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\(^3\) \( \text{CH}_4 \) kg\(^{-1} \) of VS excreted

0.67 = conversion factor of m\(^3\) \( \text{CH}_4 \) to kilograms \( \text{CH}_4 \)

\( MCF(S,k) \) = 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
Choice of emission factors (4)

- For Tier 2 method while some default values have been provided in the IPCC Guidelines, country-specific values of parameters Bo, VS and MCF should be used as far as possible as the default values may not encompass the potentially wide variations in these values according to national circumstances.
Choice of activity data

• Tier 1 method requires collection of livestock population data according to basic characterization.

• Tier 2 method requires two main types of activity data:
  – animal population data
    • single livestock enhanced characterisation depending upon the most disaggregated data requirements between enteric fermentation and manure management should be adopted.
    • regional population breakdown according to for each major climatic zone along with the average annual temperature to select the EFs
  – MMS usage data
    • portion of manure managed in each MMS for each representative animal species from published literature, national surveys etc.
Methodological Tiers – Manure Management- CH4 emissions

**Tier 1.**
- A simplified method that only requires livestock population data by animal species/category and climate region or temperature, in combination with IPCC default emission factors, to estimate emissions.

**Tier 2**
- A more complex method for estimating CH4 emissions from manure management.
- Should be used where a particular livestock species/category represents a significant share of a country’s emissions.
- Requires detailed information on animal characteristics and manure management practices.

**Tier 3**
- Use country-specific methodologies using sophisticated models or measurement–based approaches to quantify emission factors.
Manure Management (CH$_4$): calculation steps for all Tiers

**Step 1:** Divide the livestock population subgroups and characterize each subgroup preferably using annual averages considering production cycles and seasonal influences on population numbers.

**Step 2:** Estimate emission factors for each subgroup in kg CH$_4$/animal/yr.

**Step 3:** Multiply the subgroup emission factors by the subgroup populations to estimate subgroup emission, and sum across the subgroups to estimate total emission.
Manure Management (N\textsubscript{2}O)

- Direct N\textsubscript{2}O emissions occur via combined nitrification and denitrification of nitrogen contained in the manure.
- The emission of N\textsubscript{2}O from manure during storage and treatment depends on the nitrogen and carbon content of manure, duration of the storage, type of treatment, acidity and moisture content.
- Indirect emissions result from volatile nitrogen losses that occur primarily in the forms of ammonia and NOx. The fraction of excreted organic nitrogen that is mineralized to ammonia nitrogen during manure collection and storage depends primarily on time, and to a lesser degree temperature.
Direct $\text{N}_2\text{O}$ from Manure Management

Direct $\text{N}_2\text{O}$ emissions from manure management is given by

$$N_{2O_D(mm)} = \left[ \sum_S \left[ \sum_T \left( N_{(T)} \cdot N_{ex(T)} \cdot MS_{(T,S)} \right) \right] \cdot EF_{3(S)} \right] \cdot \frac{44}{28}$$

Where:

$N_{2O_D(mm)}$ = Direct $\text{N}_2\text{O}$ emissions from Manure Management in the country, kg $\text{N}_2\text{O}$ yr$^{-1}$

$N_{(T)}$ = number of animals/category $T$ in the country

$N_{ex(T)}$ = annual average N excretion/head of species/category $T$, kg N animal$^{-1}$ yr$^{-1}$

$MS_{(T,S)}$ = fraction of total annual N excretion for each livestock species/category $T$ handled in MMS, $S$ in the country, dimensionless

$EF_{3(S)}$ = EF for direct $\text{N}_2\text{O}$ emissions from MMS, $S$ in the country, kg $\text{N}_2\text{O}$-N/kg N in MMS, $S$

$S$ = manure management system

$T$ = species/category of livestock

$44/28 = \text{conversion of (N}_2\text{O-N)(mm) emissions to N}_2\text{O(mm) emissions}$
Choice of emission factors

• Tier 1
  – Annual nitrogen excretion for each livestock category defined by the livestock population characterisation.
    • Country-specific values or from other countries with livestock with similar characteristics
    • IPCC defaults of N excretion rates (2006 IPCC Guidelines) could be used with typical animal mass (TAM) values
  – Default emission factors from the IPCC Guidelines
Choice of emission factors (2)

Tier 2

- Annual nitrogen excretion for each livestock category defined by the livestock population characterisation based on total annual N intake and total annual N retention data of animals.

- Country-specific emission factors that reflect the actual duration of storage and type of treatment of animal manure in each system.
Choice of activity data

• Tier 1
  – Animal population data according to basic characterization.
  – Default or country specific manure management system usage data

• Tier 2
  – Animal population data according to single enhanced characterization.
  – Country-specific manure management system usage data from national statistics or independent survey
Calculation steps for all Tiers

**Step 1:** Divide the livestock population subgroups and characterize each subgroup preferably using annual averages considering production cycles and seasonal influences on population numbers.

**Step 2:** Use default values or develop the annual average nitrogen excretion rate per head (N\text{ex}(T)) for each defined livestock species/category \( T \).

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

**Step 4:** Use default values or develop N\textsubscript{2}O emission factors for each manure management system \( S \) (EF\textsubscript{3(S)}).

**Step 5:** For each manure management system type \( S \), multiply its (EF\textsubscript{3(S)}) by the total amount of nitrogen managed (from all livestock species/categories) in that system, to estimate N\textsubscript{2}O emissions from that MMS. Then sum over all MMS.
Uncertainty assessment

• There are large uncertainties associated with the default emission factors (−50% to +100%).

• The uncertainty of Tier 2 EFs method will depend on the accuracy of the livestock characterisation (e.g., homogeneity of livestock categories), and their correspondence with national circumstances.

• Accurate and well-designed emission measurements from well characterised types of manure and manure management systems can help reduce these uncertainties further.

• Activity data uncertainty is associated with the livestock population, manure management system usage data.
Completeness

- Livestock emission estimates should cover all the major animal categories managed in the country.
  - For animals occurring in the country for which default data are not available and for which no guidelines are provided, the emissions estimate should be developed using the same general principles.
- A complete inventory should include all systems of manure management for all livestock species/categories; at a minimum, Tier 1 estimates should be provided for all major livestock categories.
Time-series consistency

- Developing a consistent time series requires collection of an internally consistent time series of livestock population statistics using techniques to ensure it.
- To ensure time-series consistency, EFs and parameters (e.g., methane conversion factors) used to estimate emissions must reflect the change in management practices and/or the implementation of GHG mitigation measures.
QA/QC

• It is *good practice* to implement general quality control checks, and expert review of the emission estimates.

• Additional quality control checks and quality assurance procedures may also be applicable, particularly for higher tier methods e.g.,
  
  – Checking population data between national and international datasets (such as FAO and national agricultural statistics databases);
  
  – Reviewing livestock data collection methods, in particular checking that livestock subspecies data were collected and aggregated correctly with consideration for the duration of production cycles;
  
  – Reviewing EFs, parameters and activity data (e.g., MCF, MMS usage data etc.) to ensure they reflect changes in management practices and mitigation measures;

Comparison of CS factors with IPCC defaults and other countries’ data
3B. LAND
Outline - FOLU

- IPCC Guidelines and managed land as a proxy
- Land use and management categories
- Carbon pools definitions
- Key IPCC principles for estimating emissions/removals
  - Tier definitions and emission factors (EF)
  - Decision trees
  - Approaches to land representation and activity data (AD)
- Data requirements for FOLU
- Methodological approaches used in the estimation of emissions/removals in FOLU sector
- Steps in preparing inventory estimates
- Cross-cutting issues
- Exercise
The use of managed land as a proxy in estimating land-based emissions and removals (E/R)

- Factors governing E/R can be both natural and anthropogenic and can be difficult to distinguish between causal factors.
- Inventory methods have to be operational, practical and globally applicable while being scientifically sound.
- IPCC Guidelines have taken the approach of defining anthropogenic greenhouse gas emissions by sources and removals by sinks 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’
- Managed land has to be nationally defined and classified transparently and consistently over time.
- GHG emissions/removals need not be reported for unmanaged land.
Six land-use categories

Stock changes of C pools are estimated and reported for the six “top-level” land-use categories

Subdivide according to national circumstances
**Living biomass**
- All living biomass above the soil incl. stem, stump, branches, bark, seeds & foliage

**Below ground biomass**
- All living biomass of live roots, often excl. fine roots of less than (suggested) 2 mm dia.

**Dead Organic Matter**

**Dead wood**
- All non-living woody biomass not litter either standing, lying on the ground, or in the soil;
- Incl. surface wood, dead roots, stumps larger than dia. used by country to distinguish from litter (e.g., 10 cm).

**Litter**
- All non living biomass of dia. < chosen by the country (e.g., 10 cm) lying dead above soil;
- Incl. litter, fumic and humic layers & live fine roots > dia. used to distinguish below ground biomass (e.g., 2 mm).

**Soil C**
- Organic C in mineral and organic soils (including peat) to a specified depth chosen by country (default depth 30 cm for Tier 1 & 2 methods)
- Incl. live fine roots if cannot be distinguished empirically
Methodological approaches used in estimation of E/R in FOLU sector - Cycle of FOLU showing flows into and out of carbon pools

- Increase - Growth
- Discrete Events – Fires etc
- Transfers between Pools
- Continuous Processes – e.g. decay

Countries can choose to account for HWP pool

- Living Biomass
- Above-Ground Biomass
- Below-Ground Biomass
- Harvested Wood Products
- Dead Wood
- Litter
- Soil Organic Matter
- Dead Organic Matter

- Countries can choose to account for HWP pool
Each land-use category is further subdivided into **land remaining in that category** (e.g., FL-FL) and **land converted from one category to another** (e.g., FL-CL) for estimation of C stock changes. The total CO2 emissions/removals from C stock changes for each LU category is the sum of those from these two subcategories.
Total estimates for GHG are made up of subdivisions of land use categories

- Land remaining in the same land use category
- Land converted from one category to that category

Total emissions from land use category
Key IPCC principles for estimating E/R

• The simplest methodological approach consists of combining information on the extent of human activity (called activity data - AD) with coefficients that quantify emissions/removals per unit activity (AF)
Three methodological Tiers

Tier 3: Higher order methods
- Detailed modeling and/or inventory measurement systems
- Data at a greater resolution
- Lower uncertainties than the previous two methods

Tier 2: A more accurate approach
- Country or region-specific values for the general defaults
- More disaggregated activity data
- Relatively smaller uncertainties

Tier 1: Simple first order approach
- Default values of the parameters from the IPCC guidelines
- Spatially coarse default data based on globally available data
- Large uncertainties & simplifying assumptions
Methodological choice - use of decision trees

1. To be repeated for each subcategory, pool and gas

2. Significant pools account for 25-30% or more of emissions/removals from the source category
Three approaches for Land Representation

Approach 1
Net area of land use for various land use categories
No tracking of land use conversions
Only know areas of each land type at beginning and end

Approach 2
Tracking of land use conversion between land use categories on a non-spatially explicit basis
Also know areas of each transition between types

Approach 3
Tracking of land use conversion on a spatially explicit basis
Know changes on each parcel of land
### Approach 1

#### Table 2.3.1
Example of Approach 1: Available land-use data with complete territorial coverage

<table>
<thead>
<tr>
<th></th>
<th>Time 1</th>
<th>Time 2</th>
<th>Land-Use Change between Time 1 and Time 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F</strong> (Forest)</td>
<td>18</td>
<td>19</td>
<td>Forest = +1</td>
</tr>
<tr>
<td><strong>G</strong> (Grassland)</td>
<td>84</td>
<td>82</td>
<td>Grassland = -2</td>
</tr>
<tr>
<td><strong>C</strong> (Cropland)</td>
<td>31</td>
<td>29</td>
<td>Cropland = -2</td>
</tr>
<tr>
<td><strong>W</strong> (Wetlands)</td>
<td>0</td>
<td>0</td>
<td>Wetlands = 0</td>
</tr>
<tr>
<td><strong>S</strong> (Settlements)</td>
<td>5</td>
<td>8</td>
<td>Settlements = +3</td>
</tr>
<tr>
<td><strong>O</strong> (Other land)</td>
<td>2</td>
<td>2</td>
<td>Other land = 0</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>140</td>
<td>140</td>
<td>Sum = 0</td>
</tr>
</tbody>
</table>

Note: F = Forest land, G = Grassland, C = Cropland, W = Wetlands, S = Settlements, O = Other land. Numbers represent area units (Mha in this example).
Approach 2

### Table 2.3.5
Simplified Land-use Change Matrix for Example Approach 2

<table>
<thead>
<tr>
<th>Final</th>
<th>Initial</th>
<th>F</th>
<th>G</th>
<th>C</th>
<th>W</th>
<th>S</th>
<th>O</th>
<th>Final sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td></td>
<td>15</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td>2</td>
<td>80</td>
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<td></td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29</td>
<td></td>
<td>29</td>
</tr>
<tr>
<td>W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td></td>
<td>8</td>
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<tr>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Initial sum</td>
<td>18</td>
<td>84</td>
<td>31</td>
<td>5</td>
<td>2</td>
<td>140</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note:
- F = Forest land
- G = Grassland
- C = Cropland
- W = Wetlands
- S = Settlements
- O = Other land

Numbers represent area units (Mha in this example).

There is no Wetlands in this example. Blank entry indicates no land use change.
Approach 3: Spatially Explicit
Ex. # 1: LU matrix: Can you fill in the missing values?

<table>
<thead>
<tr>
<th>Initial Area</th>
<th>FL</th>
<th>CL</th>
<th>GL</th>
<th>WL</th>
<th>SE</th>
<th>OL</th>
<th>Final Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Area</td>
<td>66</td>
<td>44</td>
<td>??</td>
<td>20</td>
<td>??</td>
<td>5</td>
<td>215</td>
</tr>
<tr>
<td>FL</td>
<td>50</td>
<td>2</td>
<td>6</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>??</td>
</tr>
<tr>
<td>CL</td>
<td>5</td>
<td>35</td>
<td>8</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>GL</td>
<td>3</td>
<td>7</td>
<td>??</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>WL</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>3</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>SE</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>32</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>OL</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
And the answer is...

<table>
<thead>
<tr>
<th>Initial Area</th>
<th>FL</th>
<th>CL</th>
<th>GL</th>
<th>WL</th>
<th>SE</th>
<th>OL</th>
<th>Final Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>66</td>
<td>44</td>
<td>41</td>
<td>20</td>
<td>39</td>
<td>5</td>
<td>215</td>
</tr>
<tr>
<td>Final</td>
<td>50</td>
<td>2</td>
<td>6</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>FL</td>
<td>5</td>
<td>35</td>
<td>8</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>CL</td>
<td>3</td>
<td>7</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>GL</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>3</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>WL</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>32</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>SE</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>OL</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
## Two basic inputs in calculating GHG inventories

<table>
<thead>
<tr>
<th>Emission Factors</th>
<th>Tier 1: IPCC default factors</th>
<th>Tier 2: Country Specific data for key factors</th>
<th>Tier 3: Modelling plus repeated measurements of key stocks through time</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG inventory estimates for each land category</td>
<td>Total area per category Net Changes only (Approach 1)</td>
<td>Total area per category Estimate land conversions rates (Approach 2)</td>
<td>Spatially explicit tracking of land conversions over time (Approach 3)</td>
</tr>
</tbody>
</table>

### Activities

Approaches for estimating change in area of land categories

- Total area per category Net Changes only (Approach 1)
- Total area per category Estimate land conversions rates (Approach 2)
- Spatially explicit tracking of land conversions over time (Approach 3)
FOLU Data requirements: Activity Data, e.g., Forest land – Chap 4, 2006 GL, Vol 4

i) Area of forest land remaining forest land
   • Disaggregation according to climatic region, vegetation type, species, management, age e.t.c.,
ii) Area of other land category converted to forest land
   • Disaggregation as above
iii) Forest areas affected by disturbances
iv) Forest area undergoing transition from one state to another
v) Area of forest burnt
vii) Total afforested land derived from cropland/grassland
vii) Area of land converted to forest land through
   • Natural regeneration
   • Establishment of plantations
FOLU Data requirements: Activity data: Forest Land

<table>
<thead>
<tr>
<th>Activity data</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
</tr>
</thead>
</table>
| Area of forest/plantations                         | - Data from national sources such as the Ministry of Environment/Forests/Natural Resources  
- If national source unavailable, use international data sources such as FAO and TBFRA  
- Data is normally at national aggregated level for major plantation/forest categories  
- Verify, validate and update national and international data sources | - Data largely from national sources such as the Ministry of Environment etc.  
- The data on area should be disaggregated according to different plantation/forest types at an appropriate scale | - Data from national remote sensing or satellite assessment sources  
- Data available at fine grid scales for different plantation/forest types  
- Geo-referenced forest area data to be used |
| Harvest categories or types of wood (e.g., saw logs & veneer logs, pulpwood, & other industrial roundwood) | - Data not likely to be available | - Data not likely to be available  
- If available, national aggregate biomass harvest data to be used | - Quantities of biomass harvested from different plantation / forest categories to be obtained and used |
## FOLU Data requirements: Activity Data: Forest Land contd.

<table>
<thead>
<tr>
<th>Activity data</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial harvest (quantity of different harvest categories mentioned above)</td>
<td>- FAO provides data in the form of roundwood - The roundwood data to be converted to aboveground (whole tree) biomass using biomass expansion ratio - Verify, validate and update the data source</td>
<td>- National level aggregate commercial harvest statistics to be used</td>
<td>- Country-specific commercial harvest data from different forest categories at resolution corresponding to Tier 3 forest/plantation categories to be used</td>
</tr>
<tr>
<td>Traditional fuelwood use</td>
<td>- FAO provides data on fuelwood and charcoal use - Verify, validate and update the data source</td>
<td>- National level fuelwood consumption data from national sources, at aggregate level to be used</td>
<td>- Country-specific fuelwood extraction data for Tier 3 forest/plantation categories to be used</td>
</tr>
<tr>
<td>Other wood use</td>
<td>Same approach as adopted for commercial harvest or traditional fuelwood use</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FOLU Data requirements: Emission/Removal Factors - Forest land

- The key emission/removal factors include:
  - annual biomass growth rate, carbon fraction of dry matter, biomass expansion ratio

- Biomass Expansion Ratios (BERs) as given in IPCC 2006 GL are required to convert commercial roundwood harvested biomass (in m³) to total above-ground biomass (in tonnes)
- AGB:BGB ratio is required to estimate BGB using data on AGB - the conversion ratio (R), according to 2006 GL.
- Combining tiers – Inventory experts could adopt different tiers for different emission factors
  AGB- Above Ground Biomass
  BGB- Below Ground Biomass
### FOLU Data requirements: Emission/Removal Factors - Forest Land

<table>
<thead>
<tr>
<th>Emission/removal factor</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual biomass growth rate</td>
<td>- Default values of average annual biomass growth rate to be used for each forest/plantation category from global databases</td>
<td>- Use country-specific data available for as many forest/plantation categories if country-specific data is not available for a given forest/plantation category</td>
<td>- Use annual increment data from detailed periodic forest inventory/monitoring system</td>
</tr>
<tr>
<td></td>
<td>- Verify, validate and update international data sources</td>
<td>- Use default data, if forest species-specific data are not available</td>
<td>- Use forest species-specific carbon fraction data obtained from laboratory estimations</td>
</tr>
<tr>
<td>Carbon fraction of dry matter</td>
<td>- Use default data</td>
<td>- Use default data, if forest species-specific data are not available</td>
<td></td>
</tr>
<tr>
<td>Biomass expansion ratio (BER)</td>
<td>- Use default BER to convert commercial harvest data to total aboveground biomass removed in commercial harvest</td>
<td>- Inventory experts encouraged to develop country-specific BERs for different plantation/forest categories</td>
<td>- Estimate BER values at species level</td>
</tr>
<tr>
<td></td>
<td>- BER requires conversion from m $^3$ to tons and expansion ratio to convert commercial harvest data to total biomass removed</td>
<td>- Default values to be used in the absence of national data</td>
<td>- BERs for biomass increment, growing stock and harvest differ for a given species or a stand, requiring separate estimation</td>
</tr>
</tbody>
</table>
## FOLU Data requirements: Activity Data- Cropland

<table>
<thead>
<tr>
<th>Activity data</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area converted annually</td>
<td>- Gross area converted at the national level can be obtained from national sources such as the Ministry of Environment / Forests/Natural Resources - If national source unavailable, international data sources on deforestation such as the FAO and TBFRA - Normally, average annual rates of conversion are extrapolated to the inventory year</td>
<td>- Forest/grassland area converted according to different types, available at the national level from government /ministry sources to be used - The data on area should be disaggregated according to different forest / grassland types at an appropriate scale - If direct annual estimates not available, use average annual rates of conversion</td>
<td>- Disaggregated according to forest/grassland types and geo-referenced data from periodic satellite/remote sensing assessments could be used - Countries can use direct estimates of spatially disaggregated areas converted annually</td>
</tr>
<tr>
<td>Average area converted (10-year average)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## FOLU Data requirements: Emission Factors - Cropland

<table>
<thead>
<tr>
<th>Emission factor</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
</tr>
</thead>
</table>
| Aboveground biomass before and after conversion      | - Use default coefficients to estimate carbon stock change in biomass, resulting from land use conversions  
- Default assumption is that all biomass is cleared during conversion, leading to zero biomass after conversion | - Country-specific estimates of biomass stocks before and after conversion could be generated nationally | - Biomass data from national forest inventory studies in different forest/grassland categories subjected to conversion  
- Biomass could be estimated using species-specific allometric equations  
- Geo-referenced biomass change data at finer spatial scales |
## FOLU Data requirements: Emission Factors - Cropland

<table>
<thead>
<tr>
<th>Fraction of biomass burnt on-site and off-site</th>
<th>- Country-specific fraction of biomass burnt <em>on-site</em> and <em>off-site</em> to be generated nationally - Apportion fraction of biomass carbon loss due to <em>on-site</em> and <em>off-site</em> burning from field measurements</th>
<th>- Field measurements of biomass fraction burnt <em>on-site</em> and <em>off-site</em> in different forest/grassland categories subjected to conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction of biomass oxidised</td>
<td>- Use default values</td>
<td>- Use default data, if no measurements are available</td>
</tr>
<tr>
<td>Carbon fraction of biomass</td>
<td>- Use default data</td>
<td>- Laboratory estimation of carbon fraction for different species</td>
</tr>
<tr>
<td>Fraction of biomass left to decay</td>
<td>- Use default data</td>
<td>- Field measurements of biomass left to decay in different forest/grassland categories subjected to conversion</td>
</tr>
</tbody>
</table>
GENERIC METHODOLOGICAL GUIDANCE FOR ALL LAND CATEGORIES
A simple first order approach in the IPCC Guidelines

The IPCC Guidelines make two assumptions:

A) \[ C_{\text{flux}} = \Delta C_{\text{stocks}} \]

B) Change in carbon stocks can be estimated from land use/change and management at various points in time, their impacts on carbon stocks and the biological response to them.

(IPCC 2006 GL page1.6, section 1.2.1, para 3)
CO₂ Emissions from C stock changes on land

Annual carbon stock changes as sum for all land use categories: Equation 2.1 (2006 GL, pg 2.6)

$$\Delta C_{\text{LAND}} = \Delta C_{\text{FL}} + \Delta C_{\text{CL}} + \Delta C_{\text{GL}} + \Delta C_{\text{WL}} + \Delta C_{\text{SL}} + \Delta C_{\text{OL}}$$

Annual C stock changes for a land-use category- sum of each stratum within category: Equation 2.2 (2006 GL, pg 2.7)

$$\Delta C_{\text{LU}} = \sum \Delta C_{\text{LU}_i}$$

Annual carbon stock changes for a stratum of a land-use category- sum of all carbon pools: Equation 2.3 (2006 GL, pg 2.7)

$$\Delta C_{\text{LU}_i} = \Delta C_{\text{AB}} + \Delta C_{\text{BB}} + \Delta C_{\text{DW}} + \Delta C_{\text{LI}} + \Delta C_{\text{SO}}$$
Estimating C stock changes

1. Carbon Stock in year 1 → Carbon Stock in Year 2

   Difference between carbon stocks (Stock-Difference Method)

2. Land Use type

   C uptake through Growth → Disturbances → Harvest

   Sum of gains and losses (Gain-Loss Method)
Stock-Difference Method

- Stock-Difference Method can be used where carbon stocks in relevant pools are measured at two points in time to assess carbon stock changes

\[ \Delta C = \frac{(C_2 - C_1)}{(t_2 - t_1)} \]

Where:
\( \Delta C \) = annual carbon stock change in the pool, tonnes C yr\(^{-1} \)
\( C_1 \) = carbon stock in the pool at time \( t_1 \), tonnes C
\( C_2 \) = carbon stock in the pool at time \( t_2 \), tonnes C

Equation 2.5 page 2.10, Vol 4, 2006GL
Gain-Loss Method

- Gains-Loss Method involves tracking inputs and outputs from a C pools: e.g., gains from growth (increase of biomass) and transfer of carbon from another pool (e.g., transfer of carbon from the live biomass carbon pool to the dead organic matter pool due to harvest or natural disturbances) and loss due to harvest and mortality.

\[ \Delta C = \Delta C_G - \Delta C_L \]

- \( \Delta C \) = annual carbon stock change in the pool, tonnes C yr\(^{-1} \)
- \( \Delta C_G \) = annual gain of carbon, tonnes C yr\(^{-1} \)
- \( \Delta C_L \) = annual loss of carbon, tonnes C yr\(^{-1} \)

Equation 2.4, page 2.9, Vol 4, 2006 GL
Biomass: *Land Remaining in a Land-use Category*

- Carbon stock change in biomass on Forest Land is likely to be an important sub-category due to substantial fluxes arising from management and harvest, natural disturbances, natural mortality and forest regrowth.
- Changes in C stocks in biomass pool can be estimated using either *Stock-Change* or *Gain-Loss method*.
- The *Gain-Loss Method* requires the biomass carbon loss to be subtracted from the biomass carbon gain.
- *Gain-Loss Method* is the basis of Tier 1 method, for which default values for calculation of increment and losses are provided in the IPCC Guidelines.
Annual increase in biomass carbon stocks (Gain-Loss Method), $\Delta C_G$ (Land remaining in same land use category)

$$\Delta C_G = \sum_{i, j} (A_{i,j} G_{\text{TOTAL}i,j} CF_{i,j})$$

Where:
$\Delta C_G = \text{annual increase in biomass carbon stocks due to biomass growth in land remaining in the same land-use category by vegetation type and climatic zone, tonnes C yr}^{-1}$
$A = \text{area of land remaining in the same land-use category, ha}$
$G_{\text{TOTAL}} = \text{mean annual biomass growth, tonnes d. m. ha}^{-1} \text{ yr}^{-1}$
$i = \text{ecological zone } (i = 1 \text{ to } n)$
$j = \text{climate domain } (j = 1 \text{ to } m)$
$CF = \text{carbon fraction of dry matter, tonne C (tonne d.m.)}^{-1}$

Equation 2.9 page, 2.15, Vol 4, 2006GL
Average annual increment in biomass ($G_{\text{TOTAL}}$): Tier 1

$$G_{\text{TOTAL}} = \sum \{G_W \cdot (1+ R)\}$$

Where:

$G_{\text{TOTAL}}$ = average annual biomass growth above and below-ground, tonnes d. m. ha$^{-1}$ yr$^{-1}$

$G_W$ = average annual above-ground biomass growth for a specific woody vegetation type, tonnes d. m. ha$^{-1}$ yr$^{-1}$

$R$ = ratio of below-ground biomass to above-ground biomass for a specific vegetation type, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$

(Equation 2.10- page, 2.15, Vol 4, 2006GL).
Average annual increment in biomass ($G_{\text{TOTAL}}$): Tier 2 & 3

$$G_{\text{TOTAL}} = \Sigma \{l_V \cdot \text{BCEF}_i \cdot (1 + R)\}$$

$l_V =$ average net annual increment for specific vegetation type, $m^3 \text{ ha}^{-1} \text{ yr}^{-1}$

$\text{BCEF}_i =$ biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to above-ground biomass growth for specific vegetation type, tonnes above-ground biomass growth ($m^3$ net annual increment)$^{-1}$

Biomass carbon stocks losses (Gain-Loss Method), $\Delta C_L$

$$\Delta C_L = L_{\text{wood-removals}} + L_{\text{fuelwood}} + L_{\text{disturbance}}$$

Where:
$\Delta C_L =$ annual decrease in carbon stocks due to biomass loss in land remaining in the same land-use category, tonnes C yr$^{-1}$

$L_{\text{wood-removals}} =$ annual carbon loss due to wood removals, tonnes C yr$^{-1}$

$L_{\text{fuelwood}} =$ annual biomass carbon loss due to fuelwood removals, tonnes C yr$^{-1}$

$L_{\text{disturbance}} =$ annual biomass carbon losses due to disturbances, tonnes C yr$^{-1}$

(Equation 2.11, Vol 4, Page 2.16, 2006 GL)
Ex. # 2: Can you find the biomass C pool loss/gain?

Growth = 200,000 tonnes C yr⁻¹

Loss due to Harvest = 500 tonnes C yr⁻¹

Natural disturbance losses = 2000 tonnes C yr⁻¹

Fuelwood removals = 300 tonnes C yr⁻¹
And the answer is...

\[ \Delta C_G = 200,000 \text{ tonnes C yr}^{-1} \]

\[ \Delta C_L = L_{\text{wood -removals}} + L_{\text{fuelwood}} + L_{\text{disturbance}} \]

= 500 + 300 + 2000

= 2800 \text{ tonnes C yr}^{-1}

\[ \Delta C_{\text{biomass}} = \Delta C_G - \Delta C_L \]

= 200,000 - 2800 = 197200 \text{ tonnes C yr}^{-1}
Stock Change Method

\[ \Delta C = \frac{(C_2 - C_1)}{(t_2-t_1)} \]

\[ C = \sum_{i,j} A_{ij} V_{ij} BCEF_S R_{ij} CF_{ij} \]

C = total carbon in biomass for time \( t_1 \) to \( t_2 \) \( [i = \text{ecological zone } i \ (i = 1 \text{ to } n)] \)

\( j = \text{climate domain } j \ (j = 1 \text{ to } m) \]

A = area of land remaining in the same land-use category, ha (see note below)

V = merchantable growing stock volume, m\(^3\) ha\(^{-1}\)

R = ratio of below-ground biomass to above-ground biomass, tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)\(^{-1}\)

CF = carbon fraction of dry matter, tonne C (tonne d.m.)\(^{-1}\)

BCEF\(_S\) = biomass conversion and expansion factor

Equation 2.8 a and b, page 2.12, Vol 4, 2006GL - (land remaining in same land use category)
Biomass: *Land Converted to Other Land-Use Category – (tier 2 and 3)*

\[ \Delta C_B = \Delta C_G + \Delta C_{\text{CONVERSION}} - \Delta C_L \]

Where:

\( \Delta C_B \) = annual change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr\(^{-1}\)

\( \Delta C_G \) = annual increase in carbon stocks in biomass due to growth on land converted to another land-use category, in tonnes C yr\(^{-1}\)

\( \Delta C_{\text{CONVERSION}} \) = initial change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr\(^{-1}\)

\( \Delta C_L \) = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr\(^{-1}\)

(Equation.2.15, page 2.20, Vol 4, 2006GL)
Initial change in biomass carbon stocks in *Land Converted to Other Land-Use Category* *

\[
\Delta C_{\text{CONVERSION}} = \sum_i (B_{\text{AFTER}i} - B_{\text{BEFORE}i}) \cdot \Delta A_{\text{TO OTHERS}i} \cdot CF
\]

Where:
\( \Delta C_{\text{CONVERSION}} \) = initial change in biomass carbon stocks on land converted to another land category, tonnes C yr\(^{-1}\)

\( B_{\text{AFTER}i} \) = biomass stocks on land type \( i \) immediately after conversion, t d.m. ha\(^{-1}\)

\( B_{\text{BEFORE}i} \) = biomass stocks on land type \( i \) before conversion, t d.m. ha\(^{-1}\)

\( \Delta A_{\text{TO OTHERS}i} \) = area of land use \( i \) converted to another land-use category in a certain year, ha yr\(^{-1}\)

\( CF \) = carbon fraction of dry matter, tonne C (t d.m.)\(^{-1}\)

\( i \) = type of land use converted to another land-use category

(Equation 2.16, Page 2.20, Vol 4, 2006 GL)
Change in C stocks in DOM: *Land Remaining in the Same Land Use*

- The Tier 1 assumption for both dead wood and litter pools for all land-use categories is that their stocks are not changing over time if the land remains within the same land-use category.
- Tier 2 methods for estimation of carbon stock changes in DOM pools calculate the changes in dead wood and litter carbon pools by either *Gain-Loss Method* or *Stock-Difference Method* (*GPG LULUCF* provides guidance on DOM only for FL)
- These estimates require either detailed inventories that include repeated measurements of dead wood and litter pools, or models that simulate dead wood and litter dynamics.
Gain-Loss Method

\[ \Delta C_{\text{DOM}} = [A \cdot (\text{DOM}_{\text{in}} - \text{DOM}_{\text{out}})] \cdot CF \]

A = area of managed land, ha

\( \text{DOM}_{\text{in}} \) = average annual transfer into DW/litter pool (due to mortality, slash due to harvest and natural disturbance), t d.m./ha/yr

\( \text{DOM}_{\text{out}} \) = average annual transfer out of DW/litter pool, t d.m./ha/yr

CF = carbon fraction of dry matter, tC/(t d.m.)

(Equation 2.18, page 2.23, Vol 4, 2006 GL)
**Stock-Difference Method**

\[
\Delta C_{DOM} = \left[ A \cdot \frac{(DOM_{t2} - DOM_{t1})}{T} \right] \cdot CF
\]

A = area of managed land, ha

DOM\(_{t1}\) = DW/litter stocks at time \(t_1\) for managed land, t d.m/ha

DOM\(_{t2}\) = DW/litter stocks at time \(t_2\) for managed land, t d.m/ha

T = \((t_2 - t_1)\) = time period between the two estimates of DOM, yrs.

CF = carbon fraction of dry matter, t C/(t d.m.)

(Equation 2.19, Page 2.23 Vol 4, 2006 GL)
Change in C stocks in DOM: Land Converted to Other Land-use

• The Tier 1 assumption is that DOM pools in non-forest land categories after the conversion are zero, i.e., they contain no carbon.

• The Tier 1 assumption for land converted from forest to another land-use category is that all DOM carbon losses occur in the year of land-use conversion.

• For land converted to Forest Land litter and dead wood carbon pools starting from zero carbon in those pools. DOM carbon gains on land converted to forest occur linearly, starting from zero, over a transition period (default assumption is 20 years)
Changes in soil C stocks

\[ \Delta C_{\text{soils}} = \Delta C_{\text{Mineral}} - L_{\text{Organic}} + \Delta C_{\text{Inorganic}} \]

Where:
- \( \Delta C_{\text{Soils}} \) = annual change in carbon stocks in soils, t C yr\(^{-1}\)
- \( \Delta C_{\text{Mineral}} \) = annual change in organic carbon stocks in mineral soils, t C yr\(^{-1}\)
- \( L_{\text{Organic}} \) = annual loss of carbon from drained organic soils, t C yr\(^{-1}\)
- \( \Delta C_{\text{Inorganic}} \) = annual change in inorganic carbon stocks from soils, t C yr\(^{-1}\)
  (assumed to be 0 unless using a Tier 3 approach)

Equation 2.24, page 2.29, Vol 4, 2006GL
Mineral soils

- Soil organic matter in soils is in a state of dynamic balance between inputs (litterfall and its decay/incorporation into the soil) and outputs (organic matter decay through respiration) of organic C.
- Human actions and other disturbances alter the carbon dynamics.
- IPCC default method assumes:
  - Over time, soil organic C reaches a spatially-averaged, stable value specific to the soil, climate, land-use and management practices
  - Soil organic C stock changes during the transition to a new equilibrium SOC occurs in a linear fashion
  - The change is computed based on C stock after the management change relative to the carbon stock in a reference condition (i.e., native vegetation that is not degraded or improved)
Mineral soils (2)

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

$$SOC = \sum (SOC_{REF} \cdot F_{ND/LU} \cdot F_{MG} \cdot F_I \cdot A)$$

- $T =$ Number of years between inventories (inventory time period), years (to be substituted for $D$ if $T > D$; not done in GPG-LULUCF)

- $D =$ Time dependence of stock change factors (default = 20), years

- $SOC_{REF} =$ Reference C stock for a climate-soil combination, tC/ha

- $F_{ND/LU}, F_{MG}, F_I =$ Stock change factors for natural disturbance (or land use if it is not forest), management and organic matter input (GPG-LULUCF had an adjustment factor for the forest type and none for the input regime), dimensionless

- $A =$ Area of the stratum of forest/land use (with a common climate and soil type), ha.

Equation 2.25, Page 2.30, Vol 4, 2006GL
Organic Soils

- Organic soils have organic matter accumulated over time under anaerobic conditions.
- C dynamics of organic soils are closely linked to hydrologic conditions and C stored in organic soils readily decomposes in aerobic conditions following soil drainage.
- Loss rates of organic C vary according to climate type, drainage depth, type of organic substrate and temperature.
Organic Soils (2)

\[ \Delta C_{\text{FFOrganic}} = A_{\text{Drained}} \cdot EF_{\text{Drainage}} \]

Where:

\[ \Delta C_{\text{FFOrganic}} = \text{CO}_2 \text{ emissions from drained organic soils, t C/yr} \]

\[ A_{\text{drained}} = \text{Area of drained organic soils, ha} \]

\[ EF_{\text{Drainage}} = \text{EF for CO}_2 \text{ from drained organic soils, t C/ha/yr} \]

Steps in a LULUCF Inventory Preparation

1. Divide all land into managed and unmanaged lands
2. Develop a national land classification system for six LU classes
3. Compile data on LU/LUC for each land category
4. Estimate CO2 emissions/removals and non-CO2 emissions at apt. Tier (KCA)
5. Re-estimate if higher tier recommended by KCA
6. Sum CO2 emissions and removals and non-CO2 emissions for each land use and stratum
7. Estimate uncertainties
8. Report emissions/removals in reporting tables
9. Document and archive all information
10. Set priorities for future inventories and revise KCA for future
3C. AGGREGATE SOURCES AND NON-CO2 EMISSIONS ON LAND
3C. Aggregate Sources and Non-CO₂ Emissions on Land

- Emissions from Biomass Burning
- Liming
- Urea Application
- Direct/Indirect N₂O Emissions from Managed Soils
- Indirect N₂O Emissions from Manure Management
- Rice Cultivations
Non-CO$_2$ Emissions

- The Non-CO$_2$ emissions rate is generally determined by an emission factor for a specific gas (e.g., CH$_4$, N$_2$O) and source category and an area (e.g., for soil or area burnt) that defines the emission

$$Emission = A \cdot EF$$

Where:
Emission = non-CO$_2$ emissions, tonnes of the non-CO$_2$ gas
A = activity data relating to the emission source (can be area, or mass unit, depending on the source type)
EF = emission factor for a specific gas and source category, tonnes per unit of a source
Non-CO$_2$ emissions from biomass burning

- Emissions from fire include not only CO$_2$, but also other GHGs, or precursors, due to incomplete combustion of the fuel, including carbon monoxide (CO), methane (CH$_4$), non-methane volatile organic compounds (NMVOC) and nitrogen (e.g., N$_2$O, NO$_x$) species.

- Non-CO$_2$ greenhouse gas emissions are estimated for all land use categories.
Non-CO₂ emissions from biomass burning (2)

\[ L_{\text{fire}} = A \times M_B \times C_f \times G_{\text{ef}} \times 10^{-3} \]

Where:
\( L_{\text{fire}} \) = amount of greenhouse gas emissions from fire, tonnes of each GHG e.g., CH₄, N₂O, etc.
A = area burnt, ha
\( M_B \) = mass of fuel available for combustion, tonnes ha⁻¹. This includes biomass, ground litter and dead wood. When Tier 1 methods are used then litter and dead wood pools are assumed zero, except where there is a land-use change.
\( C_f \) = combustion factor, dimensionless
\( G_{\text{ef}} \) = emission factor, g (kg dry matter burnt)⁻¹
Liming & Urea application (CO$_2$)

CO$_2$ emissions from the bicarbonates released from lime or urea application to soil

\[
\text{CO}_2-\text{C Emission} = M \times \text{EF}_{\text{lime/urea}}
\]

Where,

- $M =$ annual amount of lime/urea applied (tyr$^{-1}$)
- EF = emission factor(t CO$_2$-C/tonne of lime or urea)
CO2 Emissions from Liming

- Liming is used to reduce soil acidity and improve plant growth in managed systems (mostly agricultural land and managed forests).
- Addition of carbonates to soils in the form of lime ((e.g., calcic limestone (CaCO₃) or dolomite (CaMg(CO₃)₂) leads to CO2 emissions as the carbonate limes dissolve to release bicarbonates which evolves to CO2 and water.
- Inventories can be developed using Tier 1, 2 or 3 approaches.
- It is good practice for countries to use higher tiers if CO2 emissions from liming are a key source category.
Choice of emission factors

Tier 1
- Default IPCC emission factors (EF) are 0.12 for limestone and 0.13 for dolomite.

Tier 2
- Use of country specific data to differentiate sources with variable compositions of lime, different carbonate liming materials, overall purity and carbon content of liming materials.

Tier 3
- Tier 3 based on estimating variables emissions from year to year and depends on site specific characteristics and environmental drivers.
Choice of activity data

Tier 1
- National usage statistics for carbonate lime on amount applied to soils annually (more direct inference on application)
- Annual sales of carbonate lime to infer the amount that is applied to soils (assumes all lime is sold to farmers, ranchers and foresters, etc.) is applied during that year
- Availability computed based on new supply for the year (annual domestic mining and import records) minus exports and usage in industrial processes.

Tier 2
- In addition to tier 1 activity data, tier 2 may incorporate information on the purity of carbonates limes, site level and hydrological characteristics

Tier 3
- Model based or direct measurements-based inventories
Methodological tiers- CO2 Emissions from Liming

Tier 1.
- Estimate the total amount of carbonate containing lime applied annually to the soils in the country, differentiating between limestone and dolomite.
- Apply an overall emission factor (EF) of 0.12 for limestone and 0.13 for dolomite.
- Multiply the total amounts of limestone and dolomite by their respective emission factors and sum the two values to obtain the total CO2-C emissions.

Tier 2
- Same as in tier 1 but incorporate country specific data to derive emission factors.
- Overall emission assumed to be less than tier 1 which assumes that all C in the applied lime is emitted as CO2 in the year of application.

Tier 3
- Tier 3 methods use more sophisticated models or measurement procedures and procedural steps, including modelling carbon fluxes associated with primary and secondary carbonate mineral formation and dissolution in soils.
CO2 emissions from Urea fertilization

• Urea is applied to soils during fertilization and leads to loss of CO2 that was fixed in the industrial production process

• CO2 recovered for urea production is estimated in IPPU sector, CO2 emissions from the application of urea are estimated and reported where they occur (Energy, AFOLU, Waste)

• Inventories can be developed using tier 1, 2 and 3 approaches

• It is good practice for countries to use higher tiers if CO2 emissions from Urea fertilisation are a key source category.
Methodological tiers for CO2 emissions from Urea fertilization

**Tier 1.**
- Estimate the total amount of urea applied to soils in the country (M)
- Apply an overall EF of 0.20 for urea (equivalent to the carbon content of urea on atomic weight basis).
- Estimate the total CO2-C emission based on the product of the amount of urea applied and the emission factors
  Multiply by 44/12 to convert CO2-C into CO2

**Tier 2**
- Uses same procedural steps as tier 1 but incorporate country specific information to estimate EF

**Tier 3**
- More detailed models or measurements that incorporate the possibility of bicarbonate leaching to deep groundwater, and/or lakes and oceans
Choice of emission factors

Tier 1

- The default emission factor (EF) is 0.20 for carbon emissions from urea applications.

Tier 2

- All C in urea may not be emitted in the year of application. If sufficient data and understanding of inorganic C transformation are available, country-specific specific emission factor could be derived.
- It is good practice to document the source of information and method used for deriving country-specific values as part of the reporting process.

Tier 3

- Tier 3 approaches are based on estimating variable emissions from year to year, which depends on a variety of site specific characteristics and environmental drivers. No emission factor is directly estimated.
Choice of activity data

Tier 1

• Domestic production records and import/export data on urea can be used to obtain an approximate estimate of the amount of urea applied to soils on an annual basis (M)

• Supplemental data on sales and/or usage of urea can be used to refine the calculation, instead of assuming all available urea in a particular year is immediately added to soils

Tier 2

• In addition to tier1 information, Tier 2 may incorporate additional information on site-level and hydrological characteristics that were used to estimate the proportion of C in urea that is emitted to the atmosphere

Tier 3

• Application of dynamic models and/or a direct measurement-based inventory
Direct N$_2$O emissions from managed soils

- Nitrous oxide is produced naturally in soils through the processes of nitrification and denitrification.
- The emissions of N$_2$O due to anthropogenic N inputs occur through both a direct pathway (i.e. directly from the soils to which the N is added), and through two indirect pathways (i.e. through volatilisation as NH$_3$ and NOx and subsequent redeposition, and through leaching and runoff).
Improvements in 2006 IPCC Guidelines over GPG 2000

- Full sectoral coverage of direct/indirect N₂O emissions;
- Revised emission factors for nitrous oxide from agricultural soils based on extensive literature review; and
- Removal of biological nitrogen fixation as a direct source of N₂O because of the lack of evidence of significant emissions arising from the fixation process.
Methodological tiers- Direct $\text{N}_2\text{O}$ emissions from managed soils

**Tier 1.**
- Applies to countries in which either $\text{N}_2\text{O}$ emissions managed soils are not a key category or country-specific emission factors do not exist.
- Use of IPCC defaults with national statistics or data from international datasets.

**Tier 2**
- More detailed emission factors and corresponding activity data are available to a country than are presented in involving further disaggregation of the terms e.g., emission factors and activity data are available for the application of synthetic fertilisers and organic $\text{N}$ ($F_{SN}$ and $F_{ON}$) under different conditions.

**Tier 3**
- Tier 3 includes models and monitoring networks tailored to address national circumstances in relation to soil and environmental variables, repeated over time, driven by high-resolution activity data and disaggregated at sub-national level. Models should be validated by representative experimental models.
Decision tree for direct N$_2$O from soils
Choice of emission factors

• Three emission factors required:
  – $EF_1$ represents the amount of $N_2O$ emitted from the various nitrogen additions to soils;
  – $EF_2$ represents the amount of $N_2O$ emitted from cultivation of organic soil; and
  – $EF_{3_{PRP}}$ estimates the amount of $N_2O$ emitted from urine and dung N deposited by grazing animals on pasture, range and paddock.

• Country-specific factors should be used as far as possible in order to reflect the specific conditions of a country and the agricultural practices involved with suitable disaggregation.

• Data from countries with similar conditions or IPCC defaults can be used if national data is unavailable.
Choice of activity data

• Several types of activity data are required:
  – N inputs from application of synthetic fertilisers ($F_{SN}$), animal manure ($F_{AM}$)
  – mineralisation of crop residues returned to soils ($F_{CR}$)
  – soil nitrogen mineralisation due to cultivation of organic soils ($F_{OS}$)
  – Urine and dung from grazing animals ($F_{PRP}$)

• The data sources are:
  – Synthetic fertiliser consumption data ($F_{SN}$) should be collected from official statistics (e.g. national bureaux of statistics) or International Fertiliser Industry Association (IFIA), FAO.
  – $F_{AM}$ should be calculated from the manure excreted and managed in MMS
  – $F_{CR}$ from crop production data (national or FAO) and IPCC default fractions.
  – The area (in hectares) of organic soils cultivated annually ($F_{OS}$) can be obtained from official national statistics.
  – Urine and dung from grazing animals ($F_{PRP}$) can be calculated from number of livestock and N excretion rates.
Direct N$_2$O emissions from managed soils (2)

\[
N_{2O_{\text{Direct}}} - N = N_{2O} - N_{\text{N inputs}} - N_{2O} - N_{\text{OS}} - N_{2O} - N_{\text{PRP}}
\]

\[
N_{2O} - N_{\text{N inputs}} = \frac{[F_{IN} - F_{ON} - F_{CR} - F_{OM}] \cdot EF_1}{[F_{IN} - F_{ON} - F_{CR} - F_{OM}] \cdot FR \cdot EF_{FR}}
\]

\[
N_{2O} - N_{\text{OS}} = \frac{[F_{O2} \cdot CG \cdot Temp \cdot EF_{2CG \cdot Temp}]}{[F_{O2} \cdot F \cdot Temp \cdot NR \cdot EF_{2F \cdot Temp \cdot NR}]} - \frac{[F_{O2} \cdot F \cdot Temp \cdot XP \cdot EF_{2F \cdot Temp \cdot XP}]}{[F_{O2} \cdot F \cdot Temp \cdot XP]} - \frac{[F_{O2} \cdot F \cdot Temp \cdot XP \cdot EF_{2F \cdot Temp \cdot XP}]}{[F_{O2} \cdot F \cdot Temp \cdot XP \cdot EF_{2F \cdot Temp \cdot XP}]}\]

Where:

- $N_{2O_{\text{Direct}}} - N$ = annual direct N$_2$O–N emissions produced from agricultural soils, kg N$_2$O–N yr$^{-1}$
- $N_{2O} - N_{\text{N inputs}}$ = annual direct N2O–N emissions from N inputs to agricultural soils, kg N2O–N yr$^{-1}$
- $N_{2O} - N_{\text{OS}}$ = annual direct N$_2$O–N emissions from agricultural organic soils, kg N$_2$O–N yr$^{-1}$
- $N_{2O} - N_{\text{PRP}}$ = annual direct N$_2$O–N emissions from urine and dung inputs to grazed soils, kg N$_2$O–N yr$^{-1}$
- $F_{SN}$ = annual amount of synthetic fertiliser N applied to agricultural soils, kg N yr$^{-1}$
- $F_{ON}$ = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to agricultural soils, kg N yr$^{-1}$
- $F_{CR}$ = annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N yr$^{-1}$
$F_{SOM}$ = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr$^{-1}$

$F_{OS}$ = annual area of managed/drained agricultural organic soils, ha (Note: the subscripts CG, Temp, Trop, NR and NP refer to Cropland and Grassland, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)

$F_{PRP}$ = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr$^{-1}$ (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

$EF_1$ = emission factor for $N_2O$ emissions from N inputs, kg $N_2O$–N (kg N input)$^{-1}$ (Table 11.1)

$EF_{1FR}$ is the emission factor for $N_2O$ emissions from N inputs to flooded rice, kg $N_2O$–N (kg N input)$^{-1}$ (Table 11.1)

$EF_2$ = emission factor for $N_2O$ emissions from drained/managed organic soils, kg $N_2O$–N ha$^{-1}$ yr$^{-1}$;

(Note: the subscripts CG, Temp, Trop, NR and NP refer to Cropland and Grassland, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)

$EF_{3PRP}$ = emission factor for $N_2O$ emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg $N_2O$–N (kg N input)$^{-1}$; (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)
Indirect N$_2$O emissions from managed soils

- In addition to the direct emissions of N$_2$O from managed soils that occur through a direct pathway (i.e., directly from the soils to which N is applied), emissions of N$_2$O also take place through two indirect pathways:
  - volatilisation of N as NH$_3$ and oxides of N (NOx), and the re-deposition as NH$_4^+$ and NO$_3^-$ onto soils and the surface of lakes and other waters;
  - leaching and runoff from land of N.
Volatilisation (N$_2$O)

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

Where:

$N_2O_{(ATD)} - N$ = annual amount of N$_2$O–N produced from atmospheric deposition of N volatilised from soils, kg N$_2$O–N yr$^{-1}$

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

Frac$_{GASF}$ = fraction of synthetic fertiliser N that volatilises as NH$_3$ and NOx, kg N volatilised (kg of N applied)$^{-1}$

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

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

Frac$_{GASM}$ = fraction of applied organic N fertiliser materials ($F_{ON}$) and of urine and dung N deposited by grazing animals ($F_{PRP}$) that volatilises as NH$_3$ and NOx, kg N volatilised (kg of N applied or deposited)$^{-1}$

$EF_4$ = emission factor for N2O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N2O (kg NH3–N + NOx–N volatilised)$^{-1}$]
Leaching/Runoff ($N_2O$)

\[ N_2O_{(L)} - N = (F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) \times \text{Frac}_{LEACH-(H)} \times EF_5 \]

Where:

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

$F_{SN} =$ annual amount of synthetic fertiliser $N$ applied to soils in regions where leaching/runoff occurs, kg $N$ yr\(^{-1}\)

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

$F_{PRP} =$ annual amount of urine and dung $N$ deposited by grazing animals in regions where leaching/runoff occurs, kg $N$ yr\(^{-1}\)

$F_{CR} =$ amount of $N$ in crop residues (above- and below-ground), including $N$-fixing crops, and from forage/pasture renewal, returned to soils annually in regions where leaching/runoff occurs, kg $N$ yr\(^{-1}\)

$F_{SOM} =$ annual amount of $N$ mineralised in mineral soils associated with loss of soil C from soil organic matter as a result of changes to land use or management in regions where leaching/runoff occurs, kg $N$ yr\(^{-1}\)

Frac\(_{LEACH-(H)} =$ fraction of all $N$ added to/mineralised in 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)\(^{-1}\)
Leaching/Runoff (N$_2$O) (2)

$$N_2O_{(ATD)} - N = \left[ \sum_i \left( F_{SNi} \cdot Frac_{GASF_i} \right) + \left( F_{ON} + F_{PRP} \right) \cdot Frac_{GASM} \right] \cdot EF_4$$

Where:

$N_2O_{(ATD)} - N$ = annual amount of N$_2$O–N produced from atmospheric deposition of N volatilised from agricultural soils, kg N$_2$O–N yr$^{-1}$

$F_{SNi}$ = annual amount of synthetic fertiliser N applied to soils under different conditions i, kg N yr$^{-1}$

$Frac_{GASF_i}$ = fraction of synthetic fertiliser N that volatilises as NH$_3$ and NOx under different conditions i, kg N volatilised (kg of N applied)$^{-1}$

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

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

$Frac_{GASM}$ = fraction of applied organic N fertiliser materials ($F_{ON}$) and of urine and dung N deposited by grazing animals ($F_{PRP}$) that volatilises as NH$_3$ and NOx, kg N volatilised (kg of N applied or deposited)$^{-1}$

$EF_4$ = emission factor for N$_2$O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N2O (kg NH$_3$–N + NOx–N volatilised)$^{-1}$]
Methodological tiers

Tier 1.
- Applies to countries in which either indirect N2O emissions managed soils are not a key category or country-specific emission factors do not exist.
- Uses IPCC defaults with national statistics or data from international datasets.

Tier 2
- More detailed emission factors and corresponding activity data are available to a country than are presented in involving further disaggregation of the terms e.g., emission factors and activity data are available for the application of synthetic fertilisers and organic N (FSN and FON) under different conditions.

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

- Emission factors and parameters required for indirect N2O from soils are:
  - EF associated with volatilised and re-deposited N (EF₄)
  - EF associated with N lost through leaching/runoff (EF₅)
  - Fractions of N that are lost through volatilisation (Frac_{GASF} and Frac_{GASM}) or leaching/runoff (Frac_{LEACH-(H)})
- Country-specific values for EF₄ should be used with great caution because of the special complexity of trans-boundary atmospheric transport.
Choice of activity data

The activity data requirements for indirect N$_2$O are the same as those for direct N$_2$O from managed soils.
CH$_4$ emissions from rice

- Anaerobic decomposition of organic material in flooded rice fields produces methane (CH$_4$), which escapes to the atmosphere primarily by transport through the rice plants.
- The annual amount emitted is dependent on rice cultivar, number and duration of crops grown, soil type and temperature, water management practices, and the use of fertilisers and other organic and inorganic amendments.
**CH₄ emissions from rice**

2006GL incorporate various changes as compared to the 1996 Guidelines and the GPG2000, namely:

i) revision of emission and scaling factors derived from updated analysis of available data,

(ii) use of daily – instead of seasonal – emission factors to allow more flexibility in separating cropping seasons and fallow periods,

(iii) new scaling factors for water regime before the cultivation period and timing of straw incorporation, and

(iv) inclusion of Tier 3 approach in line with the general principles of the 2006 revision of guidelines.

v) The revised guidelines also maintain the separate calculation of N₂O emission from rice cultivation (as one form of managed soil) which is dealt with in Chapter 11.
CH$_4$ emissions from rice (2)

CH4 emissions from rice cultivation are given by:

$$CH_4_{\text{Rice}} = \sum_{i,j,k} (EF_{i,j,k} \cdot t_{i,j,k} \cdot A_{i,j,k} \cdot 10^{-6})$$

Where:

CH$_4$ Rice = annual methane emissions from rice cultivation, Gg CH$_4$ yr$^{-1}$
EF$^{ijk}$ = a daily emission factor for $i$, $j$, and $k$ conditions, kg CH$_4$ ha$^{-1}$ day$^{-1}$
t$_{ijk}$ = cultivation period of rice for $i$, $j$, and $k$ conditions, day
A$_{ijk}$ = annual harvested area of rice for $i$, $j$, and $k$ conditions, ha yr$^{-1}$
i, j, and k = represent different ecosystems, water regimes, type and amount of organic amendments, and
other conditions under which CH4 emissions from rice may vary
### CH₄ emissions from rice (3)

$$EF_i = EF_c \cdot SF_w \cdot SF_p \cdot SF_o \cdot SF_{s,r}$$

Where:

- $EF_i =$ adjusted daily emission factor for a particular harvested area
- $EF_c =$ baseline emission factor for continuously flooded fields without organic amendments
- $SF_w =$ scaling factor to account for the differences in water regime during the cultivation period
- $SF_p =$ scaling factor to account for the differences in water regime in the pre-season before the cultivation period
- $SF_o =$ scaling factor should vary for both type and amount of organic amendment applied
- $SF_{s,r} =$ scaling factor for soil type, rice cultivar, etc., if available
Methodological tiers- CH4 emission from rice cultivation

Tier 1.
- Applies to countries in which either CH4 emissions from rice cultivation are not a key category or country specific emission factors do not exist.
- The disaggregation of the annual harvest area for at least three baseline water regimes including irrigated, rainfed, and upland.
- Emissions adjusted by multiplying a baseline default emission factor by scaling factors.

Tier 2
- Follows the same calculation equation as Tier 1 but would include the use of country-specific EFs.

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

• **Tier 1**
  - A baseline emission factor for no flooded fields for less than 180 days prior to rice cultivation and continuously flooded during the rice cultivation period without organic amendments (EFc)
  - Scaling factors are used to adjust the EFc to account for the various conditions, e.g.: water regime during and before cultivation period and organic amendments

• **Tier 2**
  - country-specific emission factors from field measurements that covering the conditions of rice cultivation in the country
  - Country-specific definition of the baseline management and scaling factors for other conditions.

• **Tier 3** are based on a thorough understanding of drivers and parameters and involve advanced modeling/monitoring frameworks.
Choice of activity data

• Activity data are primarily based on harvested area statistics, available from a national statistics agency as together with information on cultivation period and agronomic practices.

• The activity data should be broken down by regional differences in rice cropping practices or water regime.

• National data is preferable but if not available, international datasets e.g., IRRI and FAOSTAT can be used especially with Tier 1 methods.

• The use of locally verified areas correlated with available data for emission factors under differing conditions such as climate, agronomic practices, and soil properties is very useful especially for higher tier methods.
Cross Cutting issues- Uncertainty Assessment

Broad sources of uncertainty are:

- Uncertainty in land-use and management activity and environmental data (land area estimates, fraction of land area burnt etc.)
- Uncertainty in the stock change/emission factors for Tier 1 or 2 approaches (carbon increase and loss, carbon stocks, and expansion factor terms)
- Uncertainty in model structure/parameter error for Tier 3 model-based approaches, or measurement error/sampling variability associated with a measurement-based inventories

Uncertainty can be reduced by: using higher tier methods; more representative parameter values; and AD at higher resolution.
Cross Cutting issues- Completeness

• To ensure completeness it is *good practice* to include all land categories, C pools and non-CO$_2$ emissions occurring in a country.

• If there are omissions, it is a *good practice* to collect additional activity data and related emission factors and other parameters for the next inventory particularly if the category/pool is a *key category*.

• It is a *good practice* to document and explain reasons for all omissions.
Cross Cutting issues- Time-series Consistency

• It is *good practice* to ensure time-series consistency by using the same sources of data and methods across the time series.
• It is a *good practice* to recalculate emissions/removals in case there are changes in the sources of data (e.g., improved data from national forest inventories) and methods using time-series consistent methods.
• Some ways of ensuring time series consistency in LULUCF are:
  – keeping track of the land transitions through a Land Use Change Matrix;
  – Keeping track of C stocks in land-use categories before and after transitions; and
  – Using a common definition of climate and soil types for all land-use categories.
  – EFs and parameters (e.g., methane conversion factors) used to estimate emissions must reflect the change in management practices
QA/QC

• It is *good practice* to perform quality control checks through Quality Assurance (QA) and Quality Control (QC) procedures, and expert review of the emission estimation procedures.

• Tier 1 QC procedures are routine and consistent checks to: ensure data integrity, correctness and completeness; identify and address errors and omissions; and to document and archive inventory material and record all QC activities.

• It is a good practice to employ additional category-specific Tier 2 QC checks especially for higher tier methods.

• QA/QC procedures should be clearly documented for each land-use subcategory (e.g., FL-FL and L-FL etc.).
**Reporting and Documentation**

- The national inventories of anthropogenic emissions and removals from LULUCF sector should be reported according to the relevant reporting guidelines in the form of reporting tables accompanied by an inventory report.

- An inventory report should clearly explain the assumptions and methodologies used to facilitate replication and assessment of the inventory by users and third parties including: basis for methodological choice, emission factors, activity data and other estimation parameters, including appropriate references and documentation of expert judgements, QA/QC plan, verification, recalculations and uncertainty assessment as well as other qualitative information in sectoral volumes.
Summary of key messages - agriculture

• Main source/sink categories are:

LIVESTOCK EMISSIONS
(i) Enteric fermentation (CH4)
(ii) Manure management (CH4 and N2O)

Non-LIVESTOCK EMISSIONS
(iii) Rice Cultivation (CH4)
(iv) Liming and Urea Application (CO2)
(v) Biomass Burning
(vi) Direct/Indirect N2O from Managed soils
Summary- FOLU Key messages

- Land use and management have significant impact on GHG E/R
- AFOLU E/R significant in most developing countries
- 2006 IPCC Guidelines refer to sources and sinks associated with GHG emissions/removals from human activities on managed land
- The flux of CO2 to/from atmosphere is assumed to be equal to changes in carbon stocks in existing biomass and soils
- Changes in carbon stocks can be estimated by establishing rates of change in land use and practices that bring about change in land use
- Estimating carbon stocks in land-use categories:
  - That remain in same land use category
  - That have been converted to another category
Summary - FOLU Key messages

• The IPCC identifies 5 carbon pools for each land use category, carbon stock changes and E/R are estimated for each of the carbon pools
• Use of Tier structure and land representation
• Select method of estimation (equations), based on tier level selected, quantify emissions/removals for each land-use category, carbon pool
• The total CO2 emissions/removals from C stock changes for each LU category is the sum of those from the two subcategories
• Cross-cutting issues
Back-up slides
C Pools: some general observations

*Land remaining Land categories*

- **Tier 1 method**
  - FL - all C pools except biomass and (drained organic) soils assumed constant
  - CL - Only DOM assumed constant (only perennial biomass considered)
  - GL/WL/SE – all pools except (drained organic) soils assumed constant
  - OL – All C pools assumed constant.
  - Default parameters for other C pools
  - *Gain-Loss* method for all C pools except mineral soils.
C Pools: some general observations (2)

**Land remaining Land** categories:

- Tier 2 method:
  - No C pool is assumed constant (except for OL)
  - Country-specific parameters with more disaggregated AD
  - *Stock-Difference* method

**Land converted** categories:

- Tier 1 method:
  - No C pools is assumed constant.
  - L-FL: DOM C stocks before conversion assumed zero
  - L-CL/GL/SE: Biomass and DOM C stocks following conversion assumed zero; mineral soil C moves to a new equilibrium in 20 years.
  - L-WL: Biomass C stocks following conversion assumed zero for L-Flooded Land

Default parameters with AD at coarser resolution.
C Pools: some general observations (3)

*Land converted* categories:

- **Tier 2 method:**
  - No C pools is assumed constant.
  - C stocks before and following conversion can be non-zero.
  - Country-specific parameters and more disaggregated AD.

- **Tier 3 method:** nationally specific complex methods involving modeling and/or measurements.
Time to “equilibrium” in carbon pools

- For lands that enter the “land converted” category, lands stay in that category for 20 years.

- After 20 years, land in the “land converted” category is removed from the “land converted” category and added to the “Land remaining” category.

- 20 years the IPCC default for the time it takes carbon pools to reach equilibrium after land-use conversion.
Example

1995

<table>
<thead>
<tr>
<th>FL-FL</th>
<th>CL-CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>GL-GL</td>
<td>S-S</td>
</tr>
<tr>
<td>C</td>
<td>D</td>
</tr>
</tbody>
</table>

2010

<table>
<thead>
<tr>
<th>No conversion</th>
<th>CL-FL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>No conversion</td>
<td>No conversion</td>
</tr>
<tr>
<td>C</td>
<td>D</td>
</tr>
</tbody>
</table>

2000

<table>
<thead>
<tr>
<th>FL-CL</th>
<th>CL-CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>GL-CL</td>
<td>S-S</td>
</tr>
<tr>
<td>C</td>
<td>D</td>
</tr>
</tbody>
</table>

2025

<table>
<thead>
<tr>
<th>??</th>
<th>??</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>??</td>
<td>??</td>
</tr>
<tr>
<td>C</td>
<td>D</td>
</tr>
</tbody>
</table>
### Example

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2000</th>
<th>2010</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FL-FL</td>
<td>CL-CL</td>
<td>No conversion</td>
<td>CL-FL</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GL-CL</td>
<td>S-S</td>
<td>No conversion</td>
<td>No conversion</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FL-FL</td>
<td>CL-CL</td>
<td></td>
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<tr>
<td>A</td>
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<td></td>
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<tr>
<td></td>
<td>GL-CL</td>
<td>S-S</td>
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<td>C</td>
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</tr>
<tr>
<td>E</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
### Example stratification with supporting data for Tier 1 emissions estimation methods

<table>
<thead>
<tr>
<th>Factor</th>
<th>Strata (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Climate</strong> (see Annex 3A.5)</td>
<td>Boreal</td>
</tr>
<tr>
<td></td>
<td>Cold temperate dry</td>
</tr>
<tr>
<td></td>
<td>Warm temperate</td>
</tr>
<tr>
<td></td>
<td>Tropical wet</td>
</tr>
<tr>
<td><strong>Soil</strong> (see Annex 3A.5)</td>
<td>High activity clay</td>
</tr>
<tr>
<td></td>
<td>Sandy</td>
</tr>
<tr>
<td></td>
<td>Organic</td>
</tr>
<tr>
<td><strong>Biomass</strong> (Ecological Zone) (see Figure 4.1, in Chapter 4)</td>
<td>Tropical rainforest</td>
</tr>
<tr>
<td></td>
<td>Tropical dry forest</td>
</tr>
<tr>
<td></td>
<td>Subtropical humid forest</td>
</tr>
<tr>
<td></td>
<td>Subtropical desert</td>
</tr>
<tr>
<td></td>
<td>Temperate steppe</td>
</tr>
<tr>
<td><strong>Management Practices</strong></td>
<td>Intensive tillage/no-till</td>
</tr>
<tr>
<td>(more than 1 may be applied to any land area)</td>
<td>Long term cultivated</td>
</tr>
<tr>
<td></td>
<td>Liming</td>
</tr>
<tr>
<td></td>
<td>High/Medium/Low input cropping</td>
</tr>
<tr>
<td></td>
<td>Improved Grassland</td>
</tr>
</tbody>
</table>
Wetlands

- Wetlands include any land that is covered or saturated by water for all or part of the year, and that does not fall into the Forest Land, Cropland, or Grassland categories.
- Guidance is restricted to Managed Wetlands where the water table is artificially changed (e.g., drained or raised) or wetlands created through human activity (i.e., damming a river).
- **2006 IPCC Guidelines and GPG LULUCF** provide guidance on two wetlands types:
  - Peatlands cleared and drained for production of peat for energy, horticultural and other uses (**Peatlands**)
  - Reservoirs or impoundments, for energy production, irrigation, navigation, or recreation (**Floated lands**)

• When the TFI produced the 2006 IPCC Guidelines it was only possible to provide guidance on a few wetland types: organic soils (mainly drained peatlands), peatlands managed for peat extraction, and limited guidance on flooded lands.

• Since then scientific knowledge has increased and the IPCC has decided it is now time to cover these missing wetlands types.

• In addition, the UNFCCC has decided to include Wetlands Drainage and Rewetting as a new elected activity in the second commitment period of the Kyoto Protocol.
The 2013 Wetlands supplement

• The 2013 Wetlands Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetland Supplement) extends the content for the 2006 IPCC Guidelines by filling in the gaps in coverage and providing updated information reflecting scientific advances, including updating emission factors.

• It covers in land organic soils and wetlands on mineral soils, coastal wetlands including mangrove forests, tidal marshes and seagrass meadows and constructed wetlands for waste water treatment.

• The coverage of the 2006 IPCC Guidelines on wetlands was restricted to peatlands drained and managed for peat extraction, conversion to flooded lands, and limited guidance for drained organic soils.
Harvested wood products (HWP)

- Harvested wood products includes all wood material (incl. bark) that leaves harvest sites.
- Slash and other material left at harvest sites is regarded as DOM in the associated chapters of the IPCC guidelines, and is NOT considered as HWP.
- HWP constitutes a reservoir and the time carbon is held in products will vary depending on the products and its uses.
- For example - fuelwood and mill residue is burnt in the year of harvest, types of papers may have a use life of less than 5 years, sawn timber panels in building could be decades or over 100yrs
Harvested wood products (HWP) – Guidance on Approaches to estimation

• The 2006 Guidelines provide several approaches for reporting the storage of carbon in HWP and subsequent release into the atmosphere

• The guidance focuses on some of the variables needed for particular approaches and shows how they can be estimated from default data or more detailed country specific data

• The guidance also assumes that the amount of woody material in use declines following a first order decay

• Provides default tier 1 methods and higher tiers

• Alternative approaches to estimate and report the contribution of HWP to annual AFOLU CO₂ E/R differ in allocation of HWP contribution between producing and consuming countries.
Harvested wood products (HWP) – IPCC generic set of annual variables used to estimate contribution of HWP to AFOLU

• In order to make estimates of the HWP contribution for the various approaches, guidance provides a generic set of annual variables that can be used to make estimates.

• These HWP variables are listed on page 12.6 and Table12.1, Vol 4, 2006 GL.

• Using estimates of these variables, the HWP contribution can be estimated for any of the proposed approaches.

• Guidelines provide guidance on when it is consistent with good practice to report a HWP Contribution value of zero when contribution is considered insignificant.

• Insignificant’ means that the annual change in carbon in HWP stocks, is less than the size of any key category.
HWP- IPCC Approaches and estimation methods

- **Approaches** describe how emissions are allocated to countries depending on production, imports and exports of HWP – thus it is the country where wood is harvested or country where wood is used that should account for the HWP- (Chapter 12, 2006 GL)

- **Estimation methods** in contrast are how the emissions and the HWP carbon stocks are estimated from national data and statistics

- There are 4 approaches outlined in the 2006GL which differ in how emissions from HWP are allocated to different countries depending on imports and exports:
  - **Stock Change Approach** - (Include emissions from all wood consumed in the country (including imports)
  - **Production Approach** (Include emissions from all wood produced in the country (including exports)
  - **Atmospheric Flow Approach** - estimates fluxes of carbon to and from the atmosphere for HWP residing within the national boundaries. All HWP residing within the national boundaries are considered, including imported wood
  - **Simple Decay Approach** - estimates fluxes of carbon to and from the atmosphere from domestically harvested woods rather than stock changes, similar to the production approach.
Estimation of Emissions/removals HWP- IPCC Default Method

- The IPCC tier 1 method for HWP is a flux method with a life time analysis.
- Based on perception that HWP stocks are not changing, i.e., the annual carbon inflow and outflow for the HWP reservoir are assumed to be equal.
- Therefore the IPCC default assumption is that inputs to the HWP reservoir equals outputs (IPCC, 2006).
- If more wood is stored than oxidised in a given year, HWP will act as sink and removals of CO2 is reported.
- If the consumption of wood decreases to a level below what is oxidised, HWP will act as a source and emissions are reported.
- Activity data on production, imports and exports are required with estimates on the lifetime of different products. (AD are from FAO)
IPCC default assumption - considers only stock changes in forests, that stock changes in HWP=0

\[ \text{Removal} = \text{Stock change} = (\text{stock change forest}) \\
= (\text{forest growth} - \text{slash} - \text{wood production}) \]
Task Force on National Greenhouse Gas Inventories

Thank you !!
Any Questions?

Guidelines in all UN languages can be downloaded from:
http://www.ipcc-nggip.iges.or.jp/