Task Force on National Greenhouse Gas Inventories

AGRICULTURE FORESTRY AND OTHER LAND USE (AFOLU)

Nalin SRIVASTAVA

IPCC TFI TSU

REGIONAL AFRICAN WORKSHOPS ON REDD+ NATIONAL FOREST MONITORING SYSTEMS AND GREENHOUSE GAS NATIONAL INVENTORY SYSTEMS

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INTERGOVERNMENTAL PANEL ON climate change

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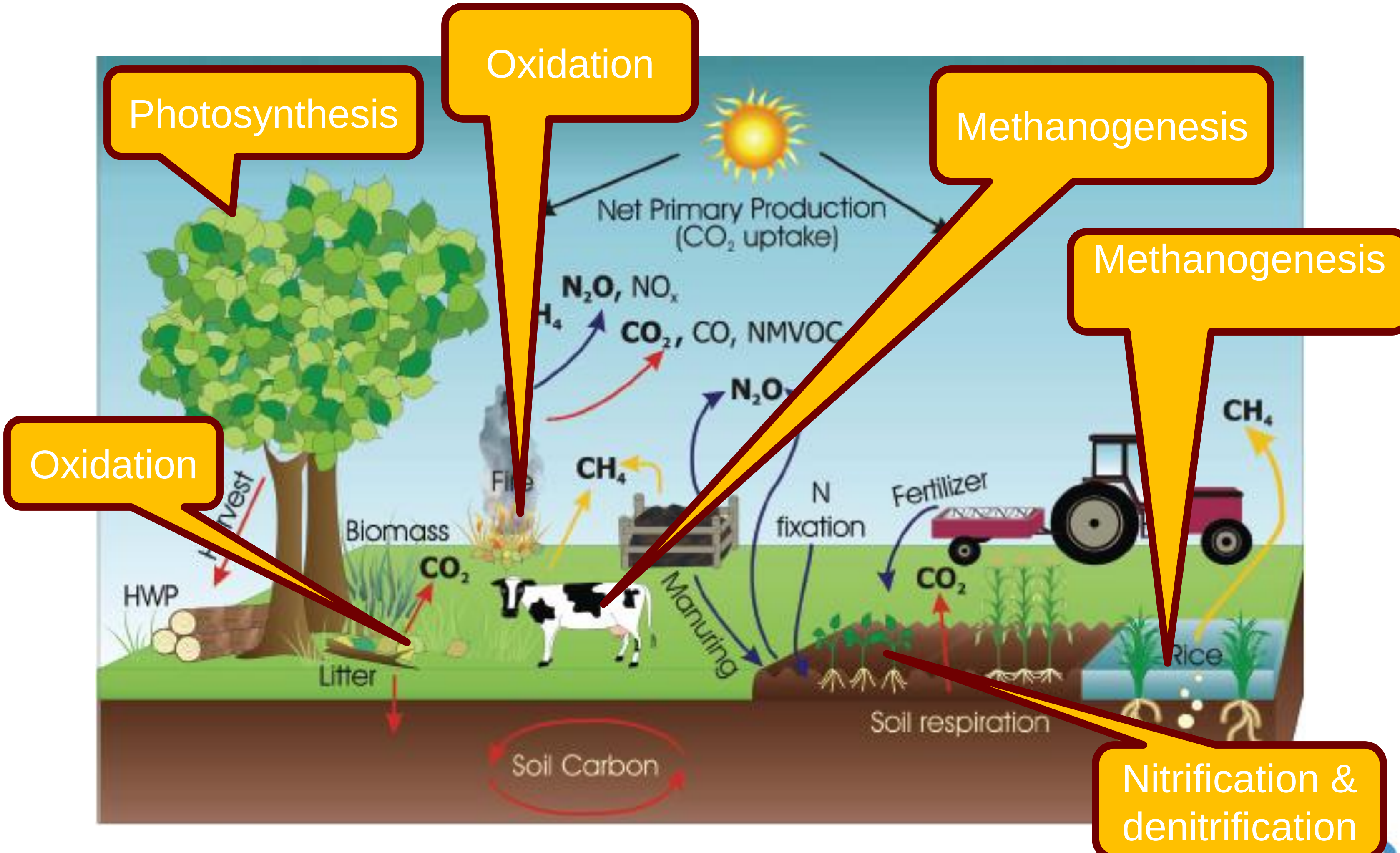
Outline

- Introduction
- IPCC Guidelines for Agriculture and land-use
- AFOLU
  - 3A. Livestock
  - 3B. Land
  - 3C. Aggregate sources and non-CO_2 emissions on land
- Cross-cutting issues
- Exercise

Introduction

- Changes due to land use change and management of the biosphere 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.
- Agriculture and land-use emissions and removals account for a very significant proportion of GHG emissions/removals in developing countries.

Terrestrial sources/sinks of GHGs



IPCC Guidelines for National Greenhouse Gas Inventories

- *Revised 1996 Guidelines -Land-Use Change and Forestry (LUCF)*
- *2000 Good Practice Guidance and Uncertainty Management*
- *Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG LULUCF)*
- *2006 IPCC Guidelines for National Greenhouse Gas Inventories*

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

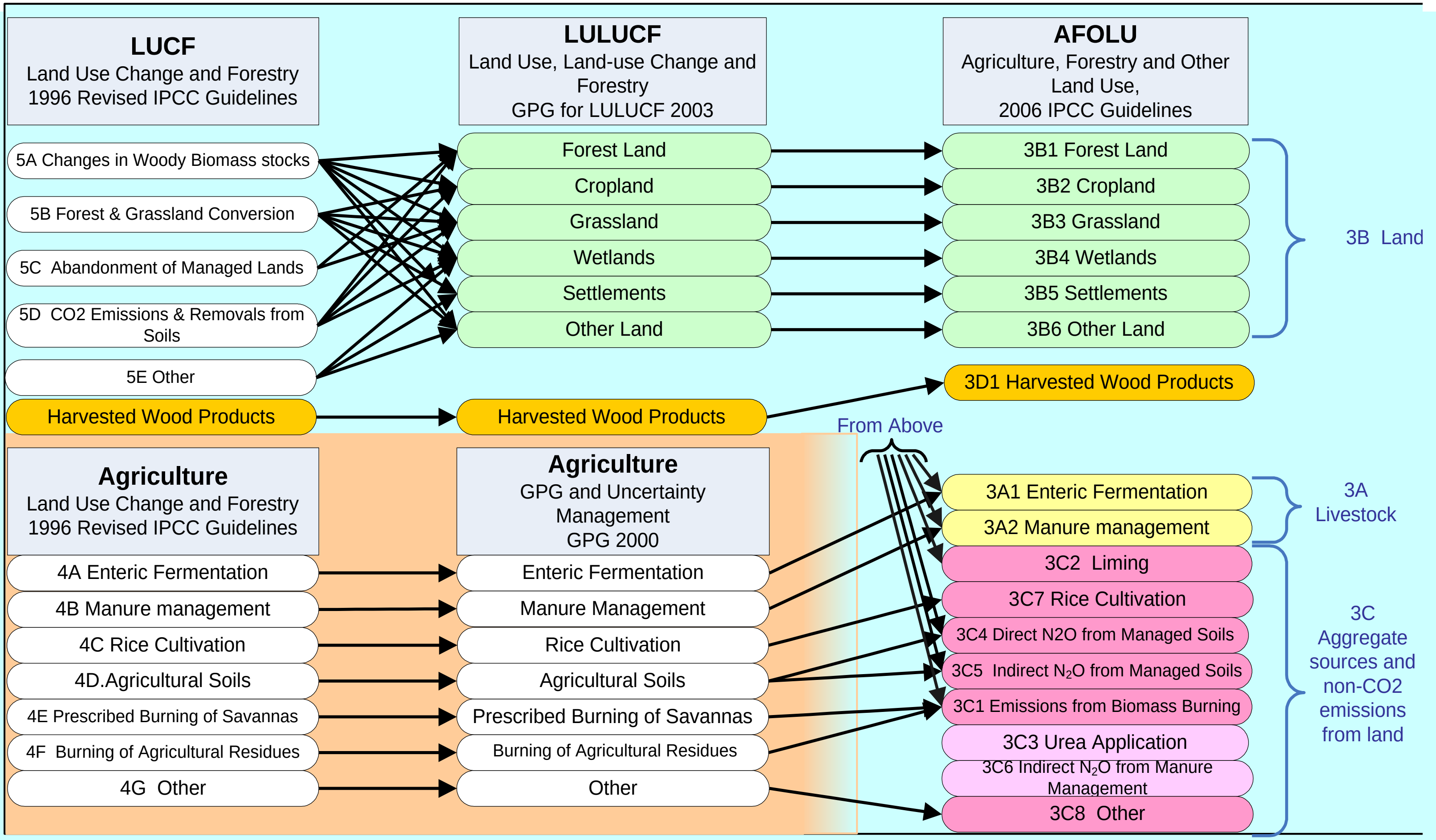
GPG & GPG-LULUCF

- **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



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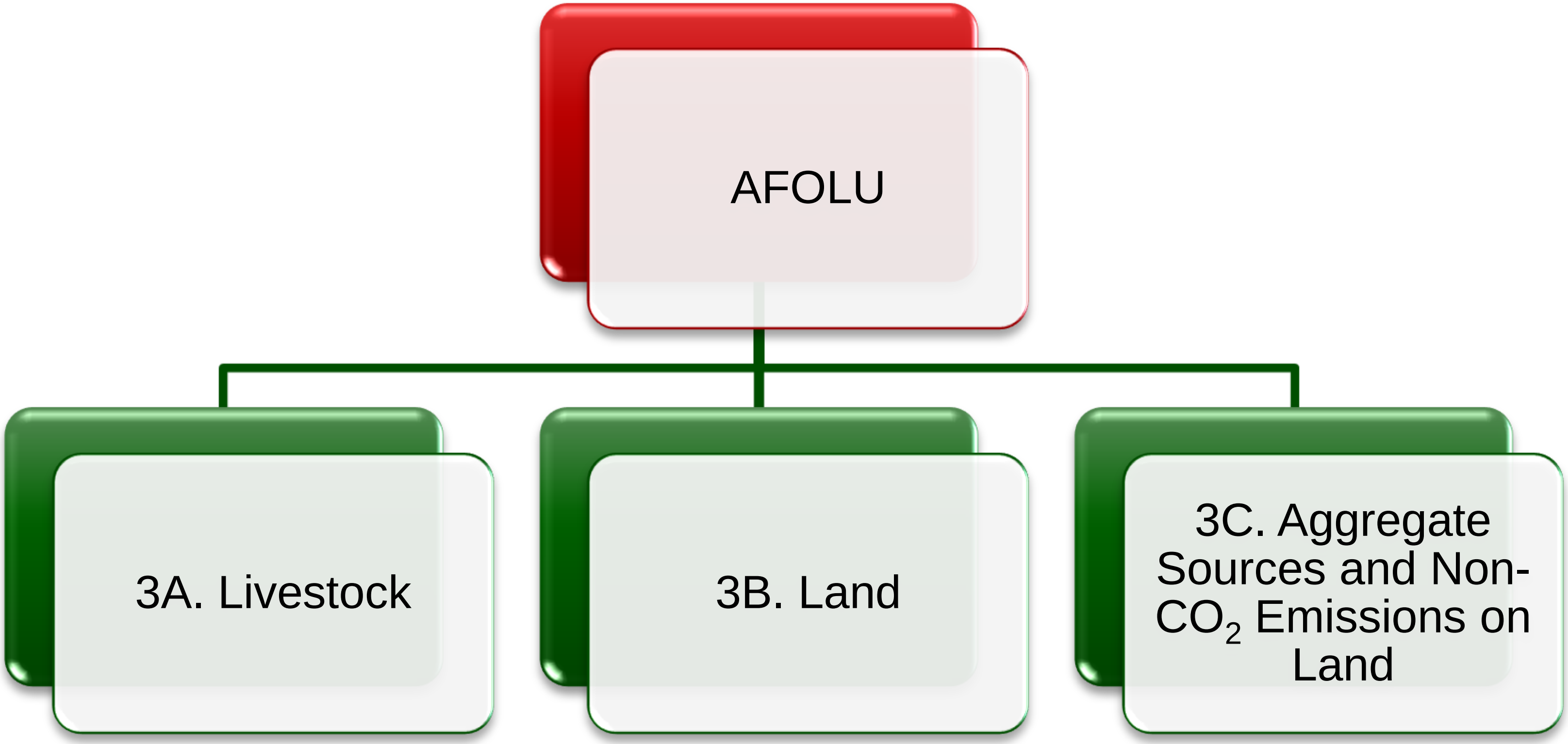
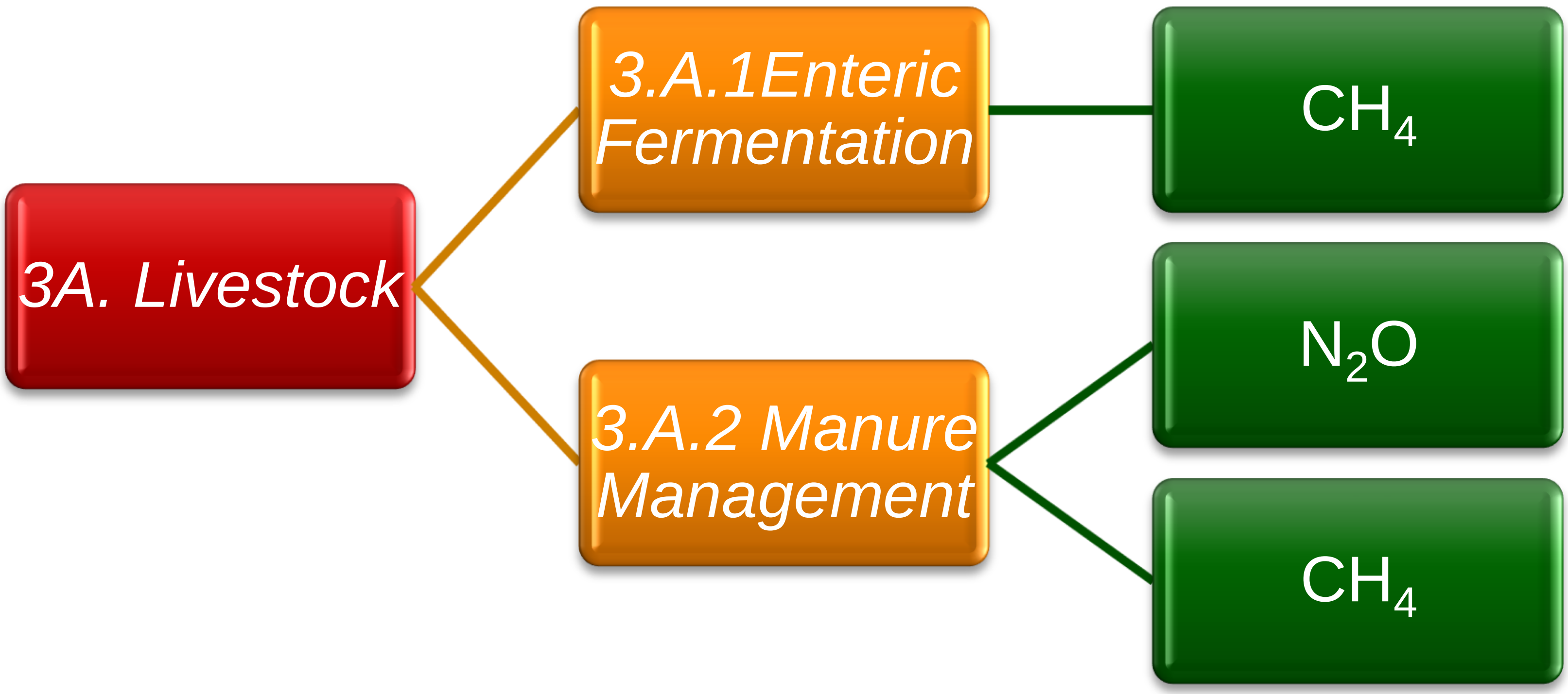
Agriculture Forestry and Other Land Use (AFOLU)

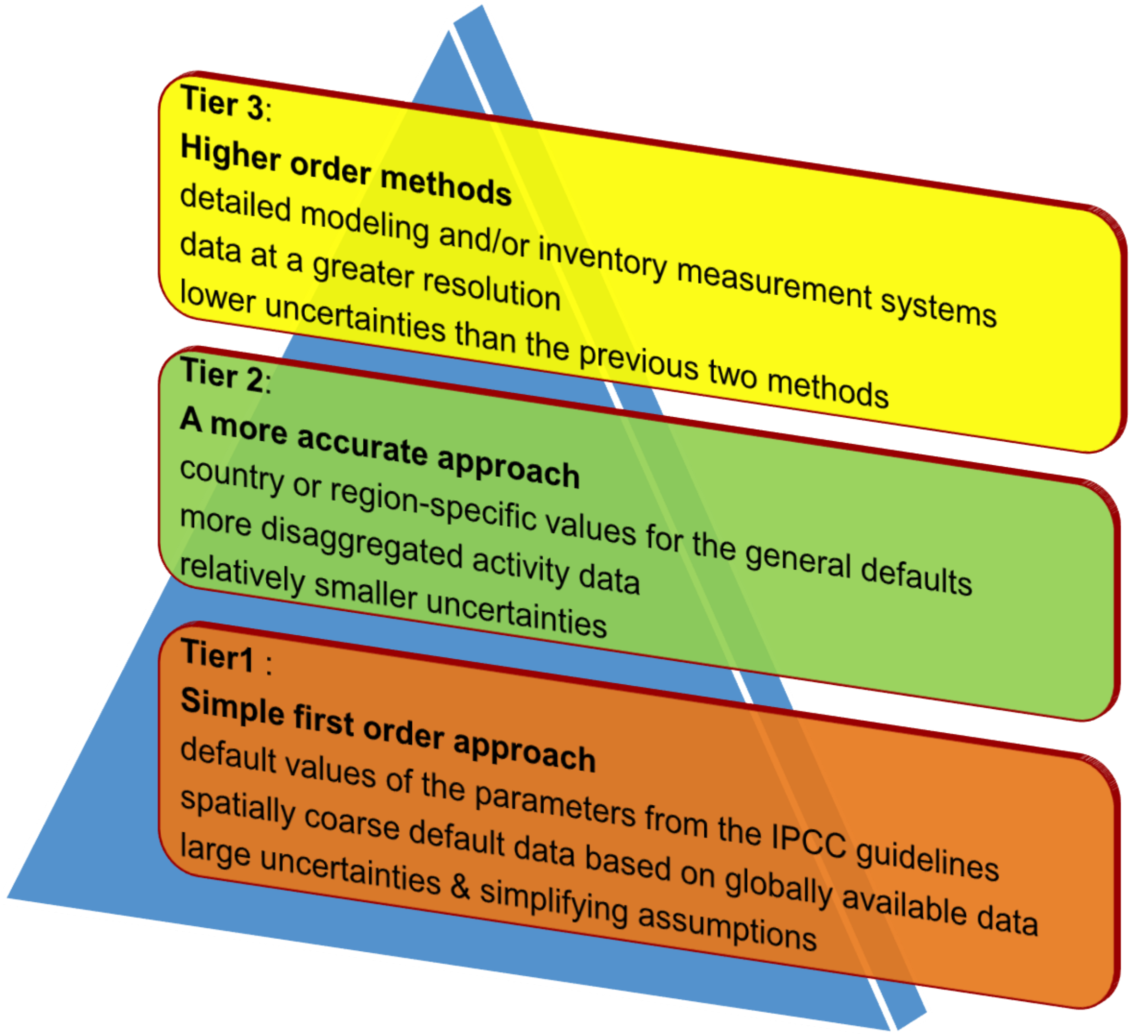



3A. LIVESTOCK

3A. Livestock emissions

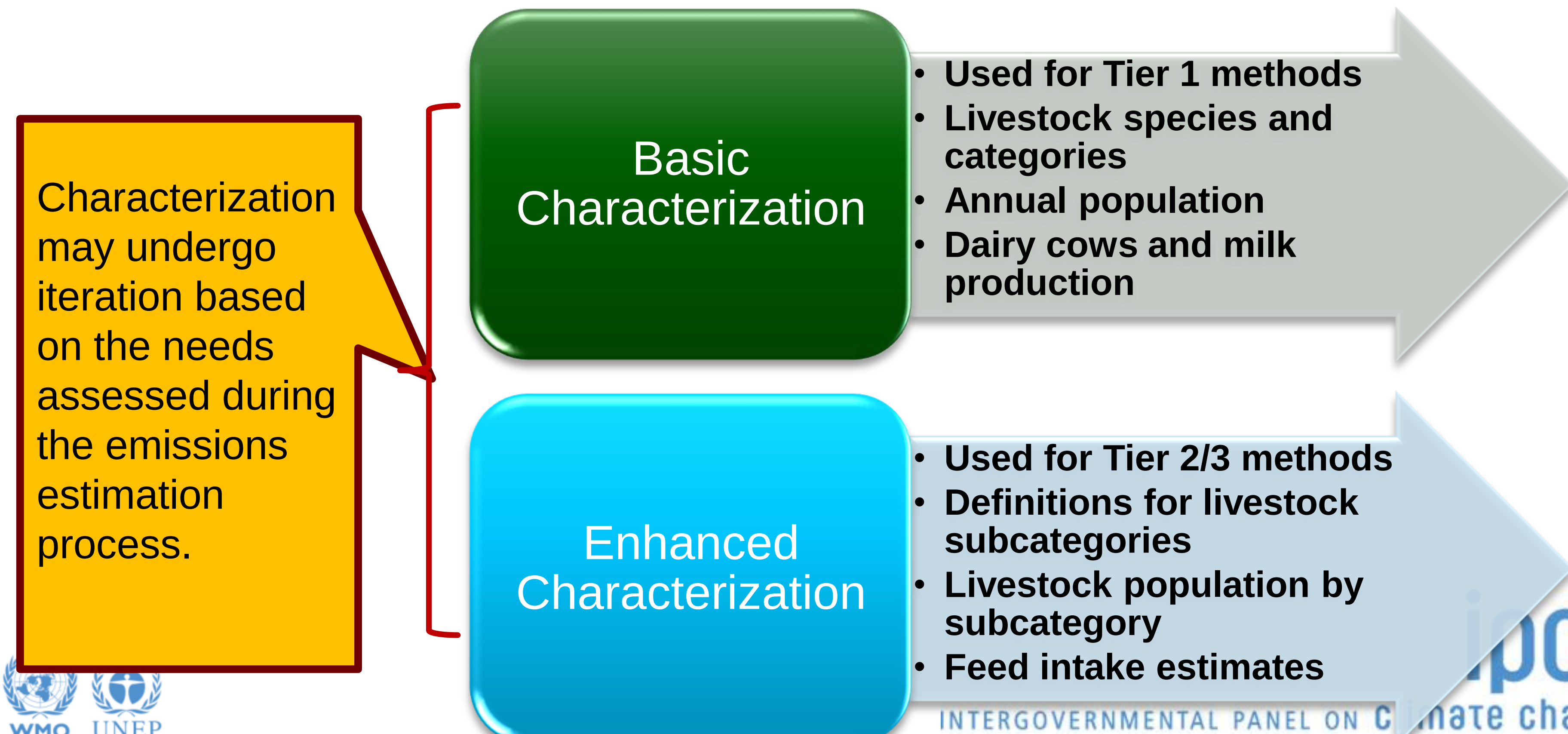


Three methodological Tiers



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.



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.

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Decision tree for livestock population characterisation

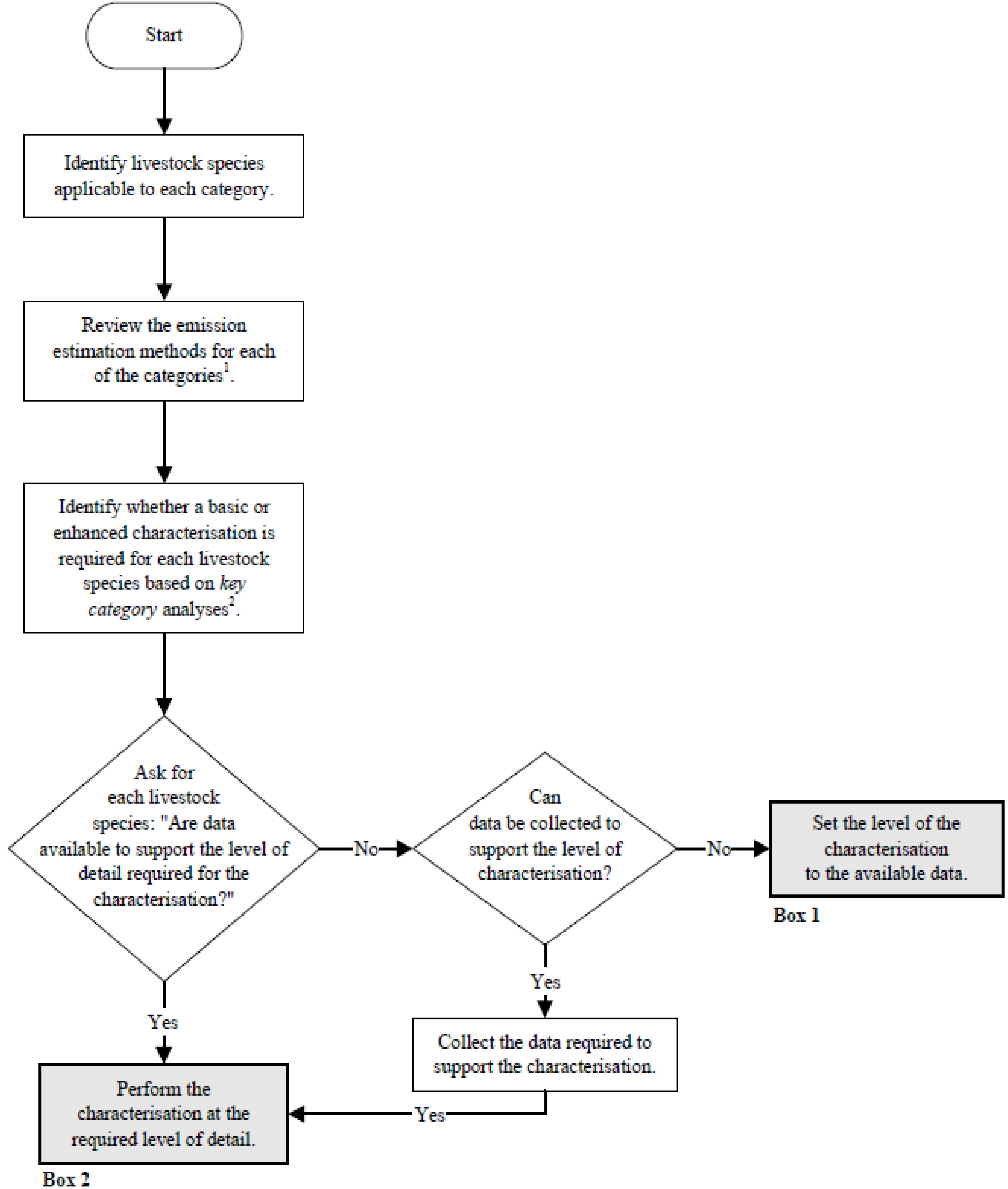

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TABLE 10.1
REPRESENTATIVE LIVESTOCK CATEGORIES[1,2]

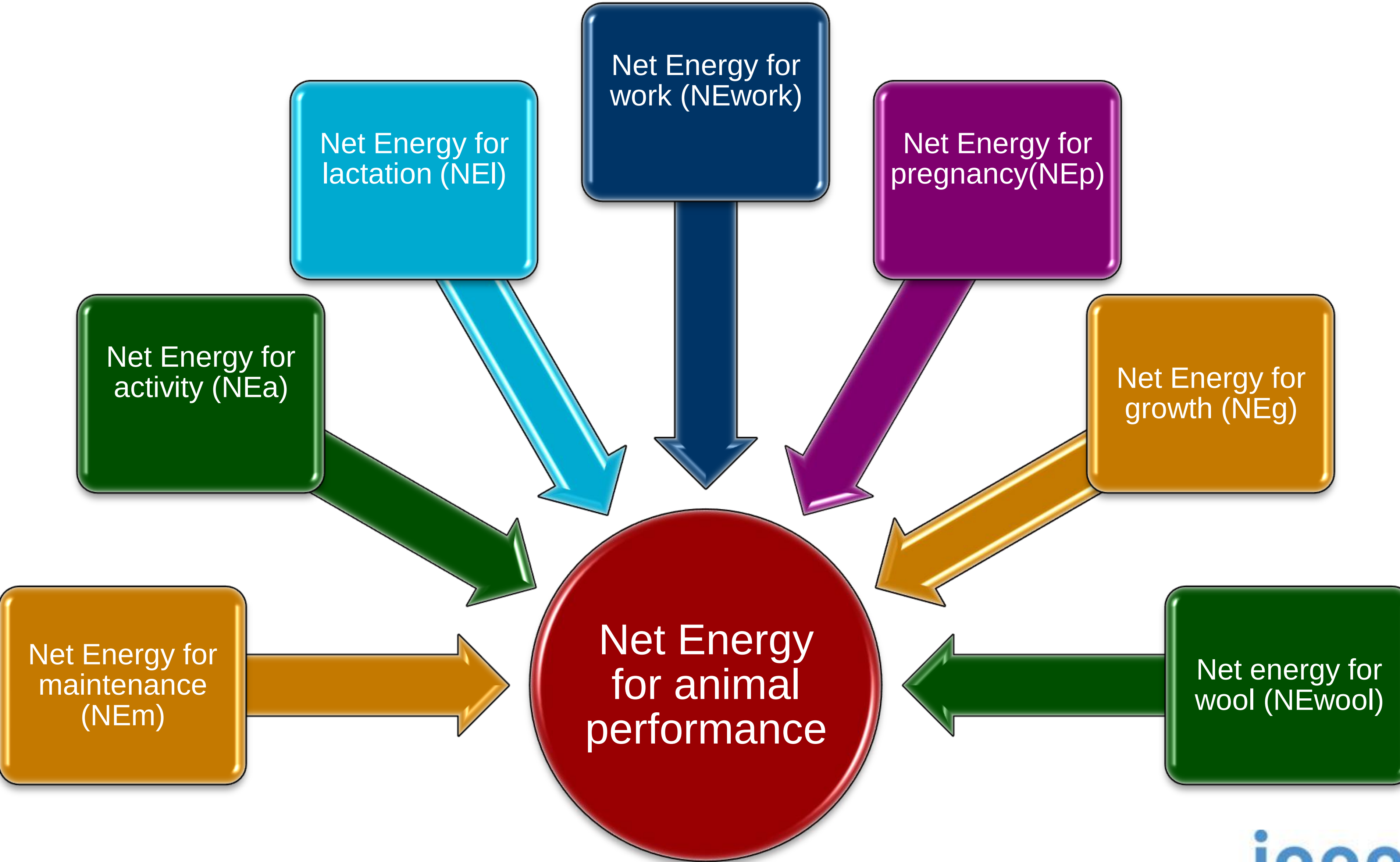
Main categories	Subcategories
Mature Dairy Cow or Mature Dairy Buffalo	• High-producing cows that have calved at least once and are used principally for milk production • Low-producing cows that have calved at least once and are used principally for milk production
Other Mature Cattle or Mature Non-dairy 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

Gross energy

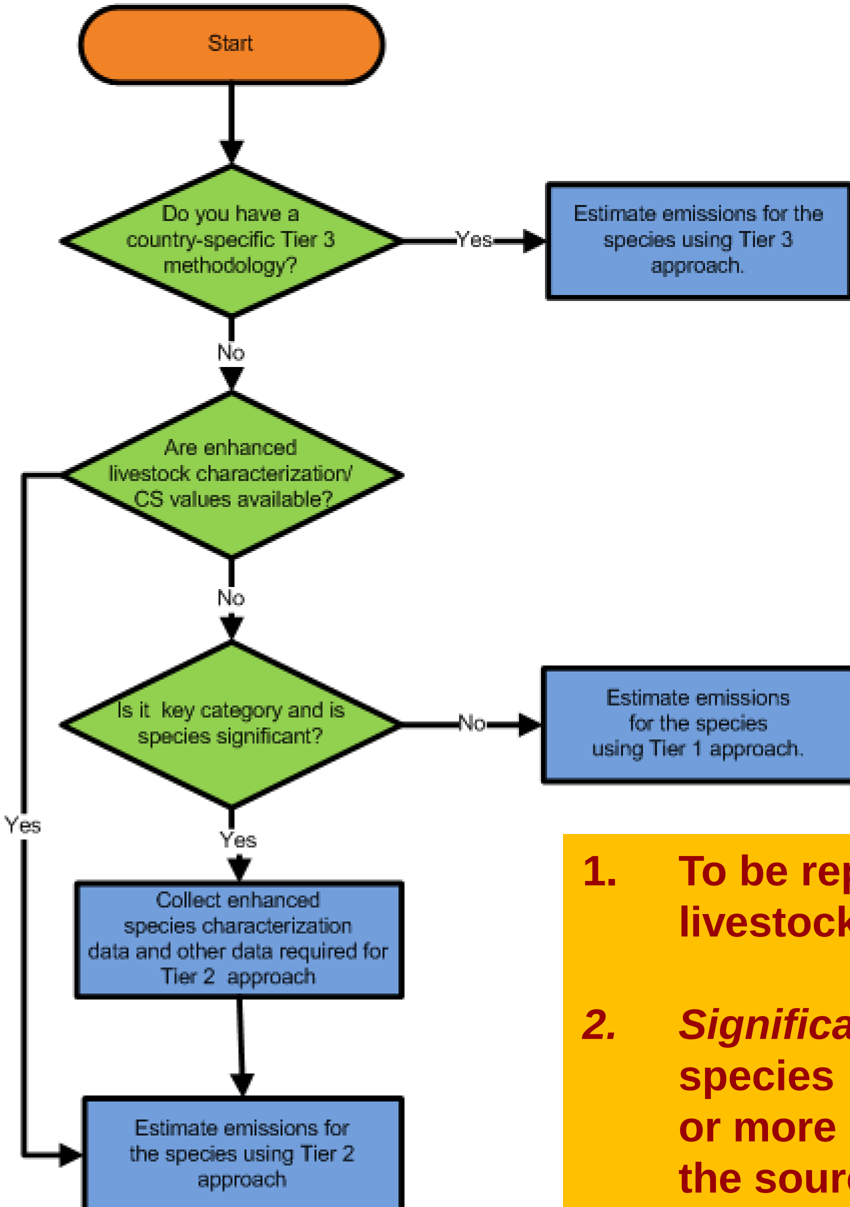
- Animal performance and diet data are used to estimate feed intake, which is the amount of Gross Energy (MJ/day) an animal needs for maintenance and for activities such as growth, lactation, and pregnancy.
- Total net energy requirement for animal performance and feed digestibility data are used to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

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.


Net Energy for work (NEwork)
Net Energy for lactation (NEl)
Net Energy for pregnancy(NEp)
Net Energy for activity (NEa)
Net Energy for growth (NEg)
Net Energy for maintenance (NEm)
Net Energy for animal performance
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**

Enteric Fermentation: Tier 1 method

$$Emissions = EF_{(T)} \bullet \left(\frac{N_{(T)}}{10^6} \right)$$

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_4Enteric = total methane emissions from Enteric Fermentation, Gg CH_4 yr^{-1}

Ei = is the emissions for the *i*th livestock categories and subcategories

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Enteric Fermentation: Tier 2 Method

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

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

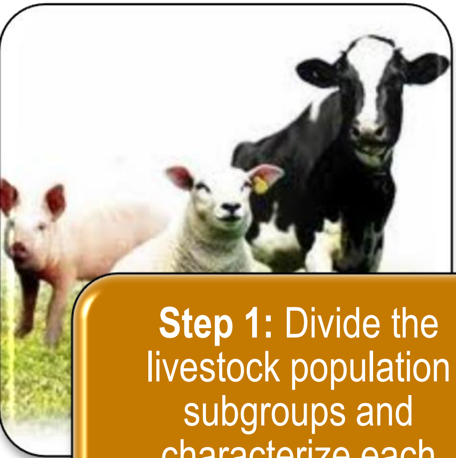
Choice of emission factors

- 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

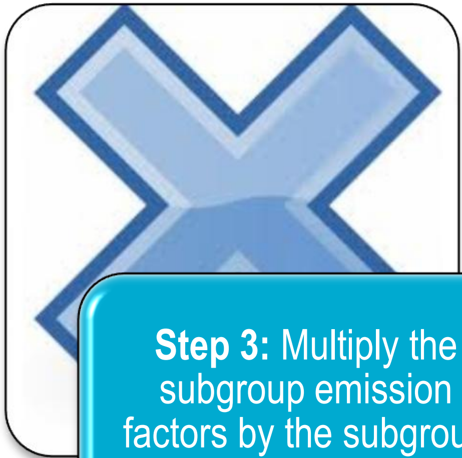
- Tier 1 method requires collection of livestock population data according to basic characterization.
- Tier 2 method requires animal population data according to single livestock enhanced characterisation depending upon the most disaggregated data requirements between enteric fermentation and manure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

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 favorable 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)

$$CH_{4Manure} = \sum_{(T)} \frac{\left(EF_{(T)} \bullet N_{(T)}\right)}{10^6}$$

Where:

$CH_{4Manure}$ = CH_4 emissions from manure management, for a defined population, Gg CH_4 yr^{-1}

EF(T) = emission factor for the defined livestock population, kg 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)
    - B_o 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)

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

Where:

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

VS(T) = daily volatile solid excreted for livestock category *T*, kg dry matter animal^{-1} day^{-1}

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

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

0.67 = conversion factor of m^3 CH_4 to kilograms CH_4

MCF(S,k) = methane conversion factors for each manure management system *S* by climate region *k*, %

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

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.

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_2O)

- Direct N_2O emissions occur via combined nitrification and de-nitrification of nitrogen contained in the manure.
- The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, 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 N_2O from Manure Management

Direct N_2O emissions from manure management is given by

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

Where:

$N_2O_{D(mm)}$) = Direct N_2O emissions from Manure Management in the country, kg N_2O 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 N_2O emissions from MMS, *S* in the country, kg N_2O-N/kg N in MMS, *S*

S = manure management system

T = species/category of livestock

44/28 = conversion of (N_2O-N)(mm) emissions to N_2O(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 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 (Nex(T)) for each defined livestock species/category T.

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

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

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

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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

Land-based emissions and removals

- 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

A simple first order approach in the IPCC Guidelines

The IPCC Guidelines make two assumptions:

A) $$C_{flux} = \Delta C_{stocks}$$

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.

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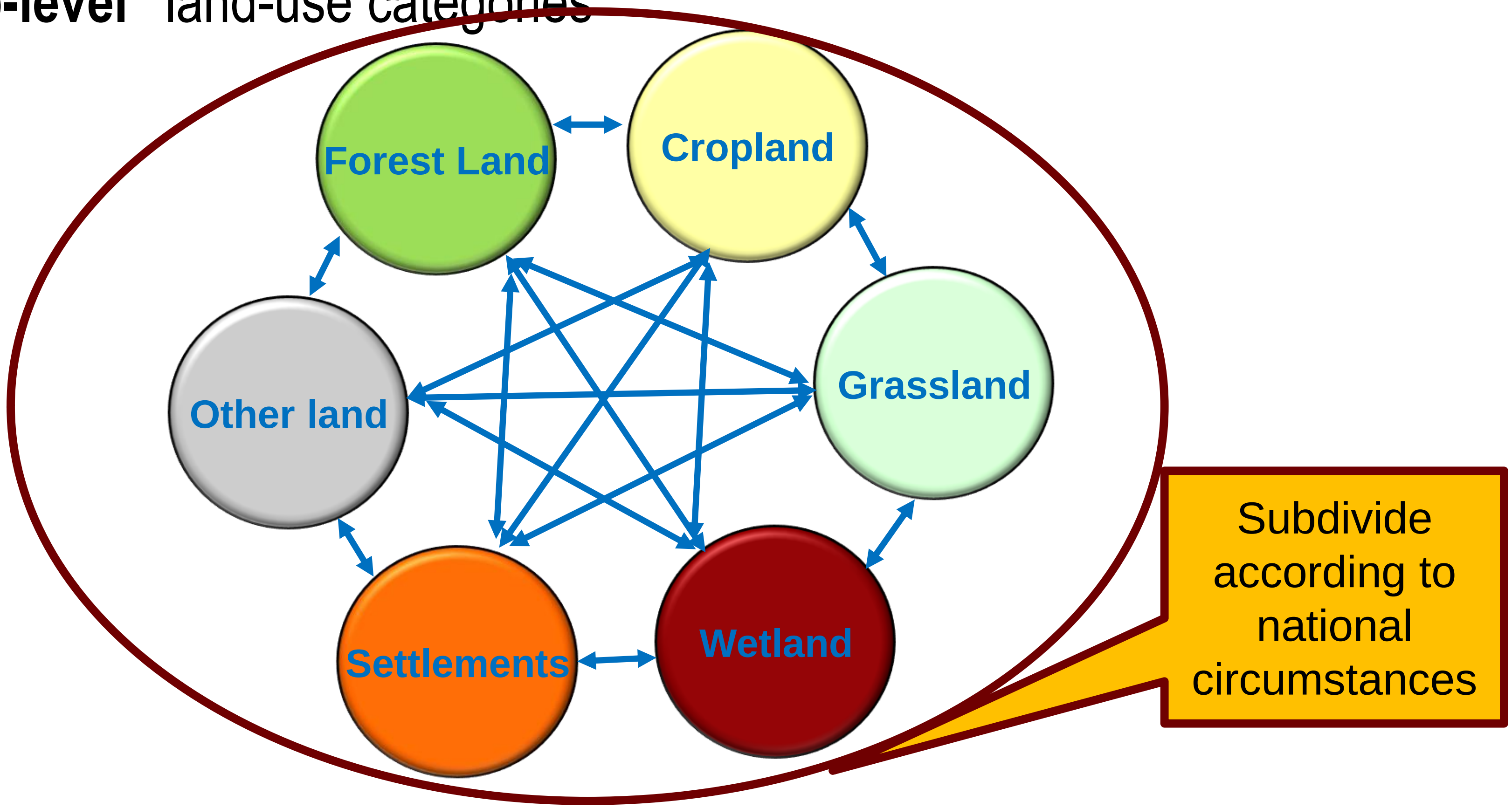
Six land-use categories

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



Carbon Pools

Living biomass

Above ground 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).

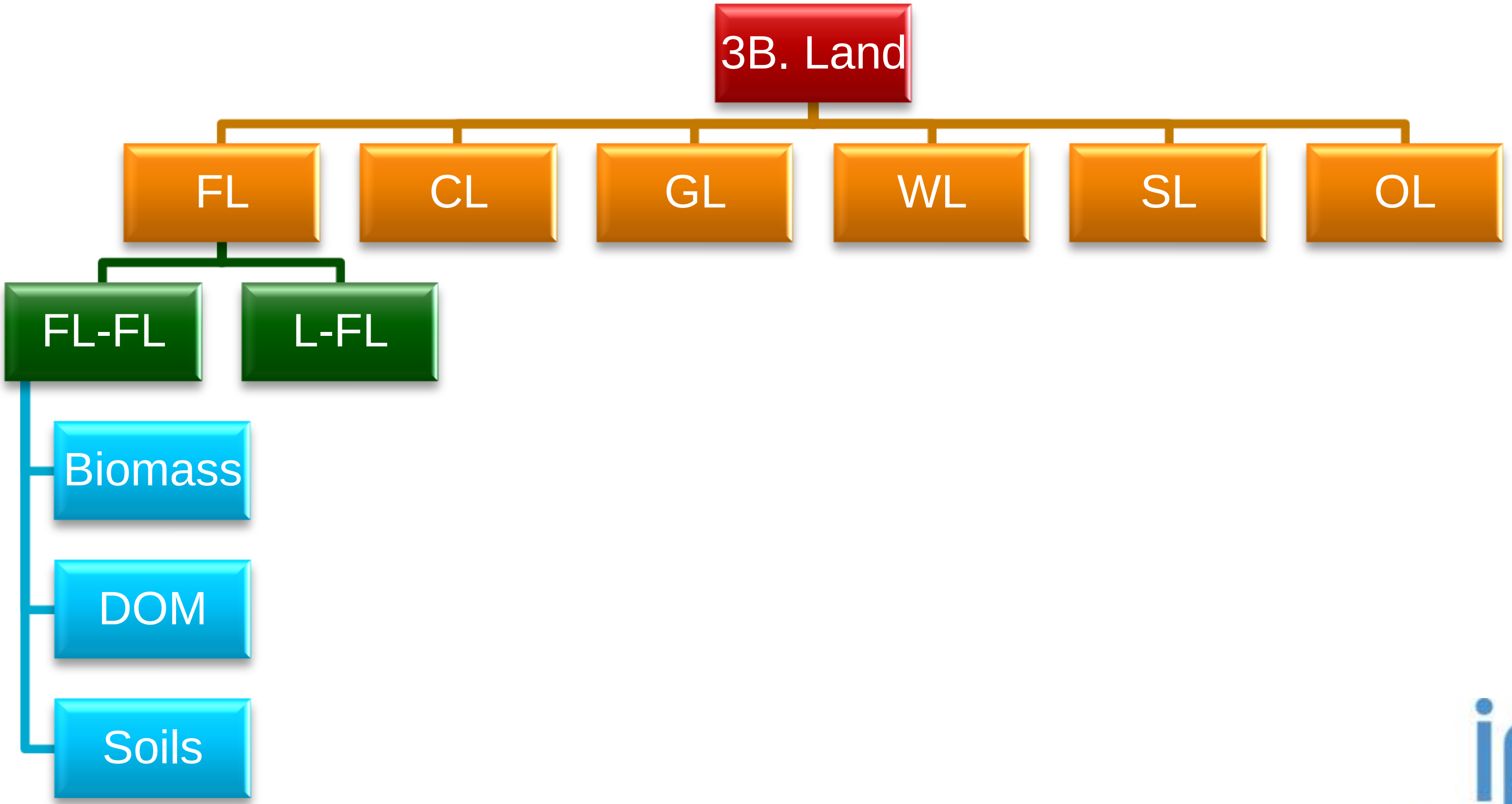
Soil C

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)

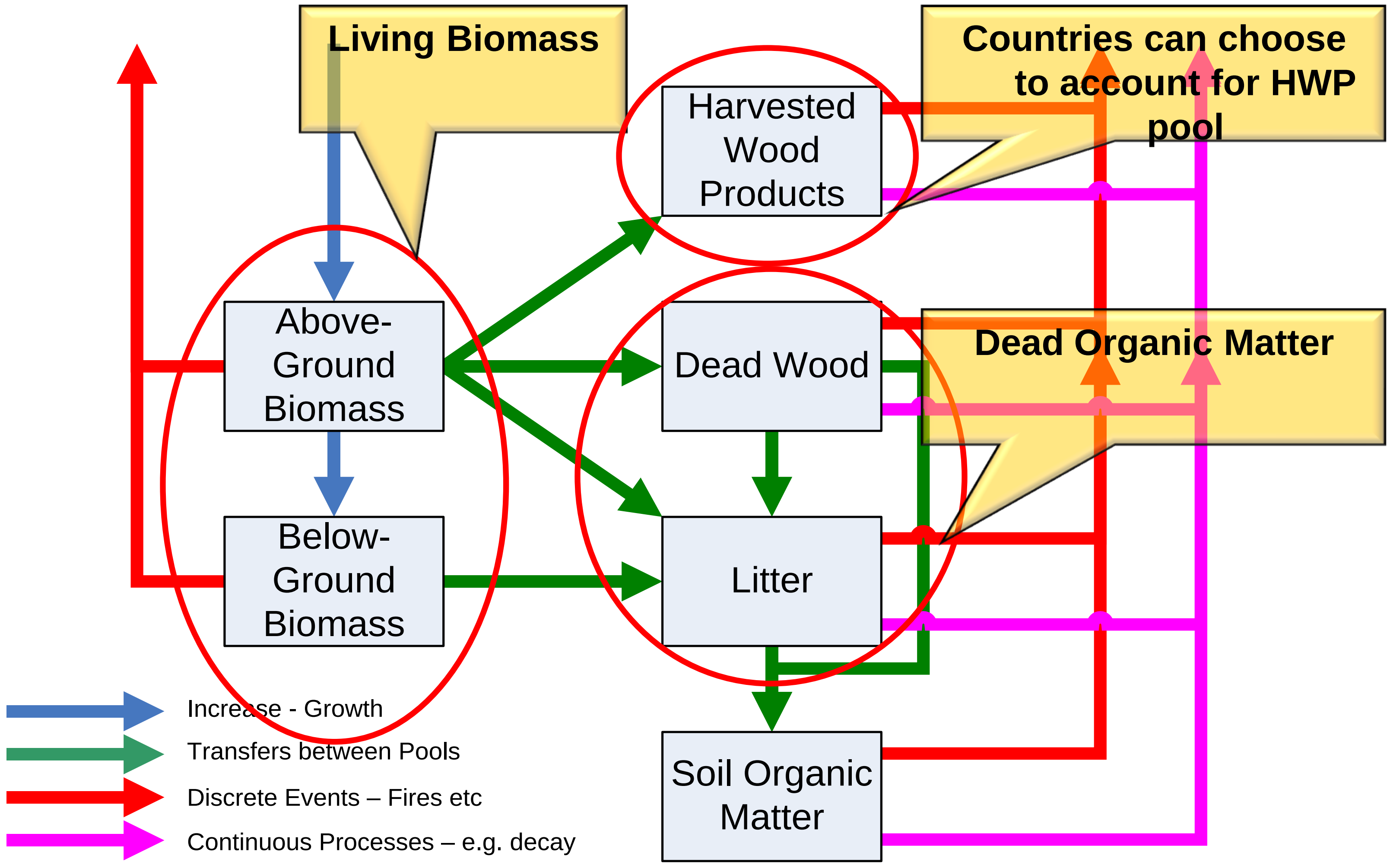
incl. live fine roots if cannot be distinguished empirically

Land-use subcategories and carbon pools

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.



C pools


Living Biomass
Harvested Wood Products
Countries can choose to account for HWP pool
Above-Ground Biomass
Below-Ground Biomass
Dead Wood
Litter
Dead Organic Matter
Soil Organic Matter
Increase - Growth
Transfers between Pools
Discrete Events – Fires etc
Continuous Processes – e.g. decay

CO_2 Emissions from C stock changes on land

Annual carbon stock changes for land :

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

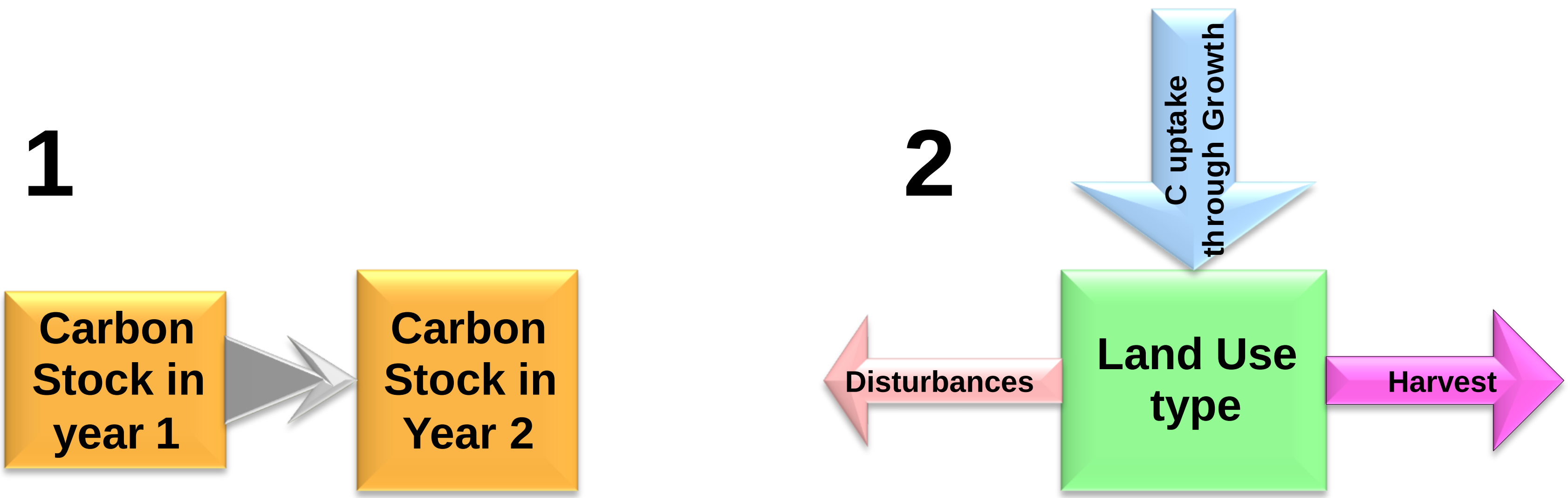
Annual C stock changes for a land-use category:

$$\Delta C_{LU} = \Sigma\, \Delta C_{LU\ i}$$

Annual carbon stock changes for a stratum of a land-use category:

$$\Delta C_{LUi} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO}$$

Estimating C stock changes



Difference between carbon stocks (Stock-Difference Method)

Sum of gains and losses (Gain-Loss Method)

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.

$$\Delta C = \Delta C_G - \Delta C_L$$

ΔC = annual carbon stock change in the pool, tonnes C yr^{-1}

ΔC_G = annual gain of carbon, tonnes C yr^{-1}

ΔC_L = annual loss of carbon, tonnes C yr^{-1}

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

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

Where:

ΔC = 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

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

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Approach 1

TABLE 2.3.1
EXAMPLE OF APPROACH 1:
AVAILABLE LAND-USE DATA WITH COMPLETE TERRITORIAL COVERAGE

Time 1			Time 2			Land-Use Change between Time 1 and Time 2		
F	=	18	F	=	19	Forest	=	+1
G	=	84	G	=	82	Grassland	=	-2
C	=	31	C	=	29	Cropland	=	-2
W	=	0	W	=	0	Wetlands	=	0
S	=	5	S	=	8	Settlements	=	+3
O	=	2	O	=	2	Other land	=	0
Sum	=	*140*	*Sum*	=	*140*	*Sum*	=	*0*

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

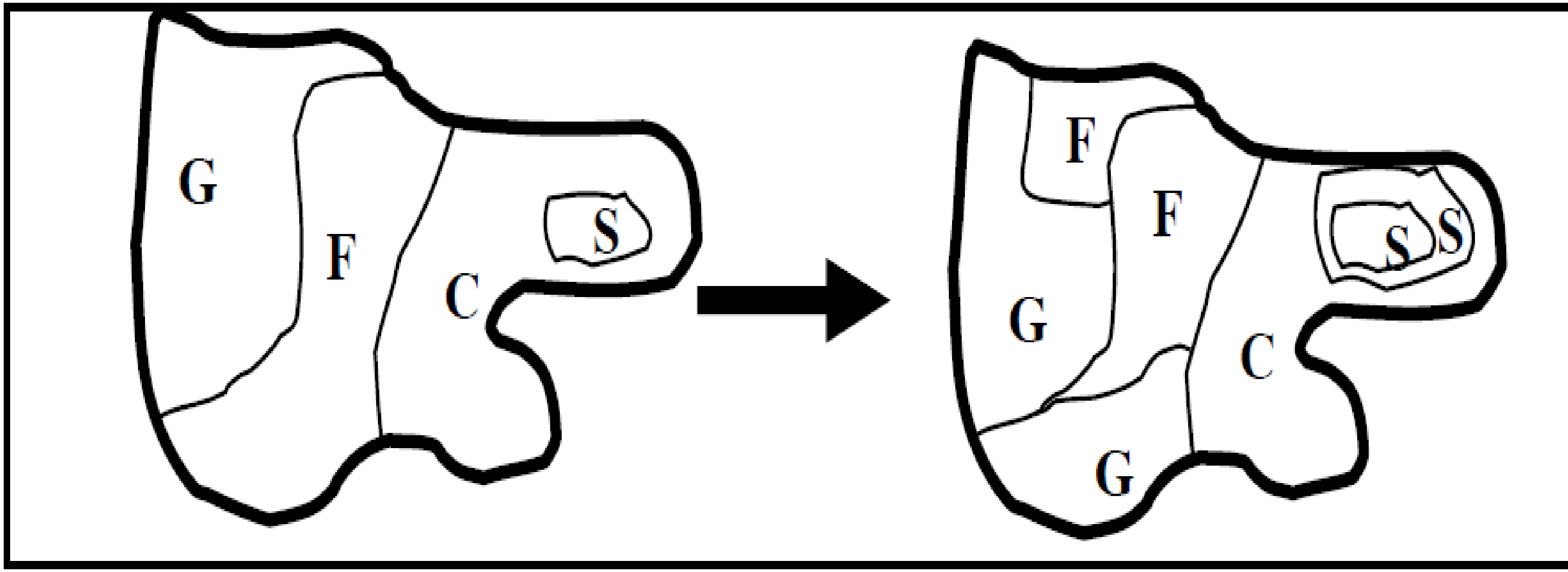
TABLE 2.3.5
SIMPLIFIED LAND-USE CHANGE MATRIX FOR EXAMPLE APPROACH 2

Land-Use Change Matrix

Initial / Final	F	G	C	W	S	O	*Final sum*
F	**15**	3	1				*19*
G	2	**80**					*82*
C			**29**				*29*
W							
S	1	1	1		**5**		*8*
O						**2**	*2*
Initial sum	*18*	*84*	*31*		*5*	*2*	*140*

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. # 2: Can you fill in the missing values?

Initial / Final	FL	CL	GL	WL	SE	OL	Final Area
FL	50	2	6	0	2	0	??
CL	5	35	8	0	2	0	50
GL	3	7	??	0	0	0	37
WL	8	0	0	20	3	0	31
SE	0	0	0	0	32	0	32
OL	0	0	0	0	0	5	5
Initial Area	66	44	??	20	??	5	215

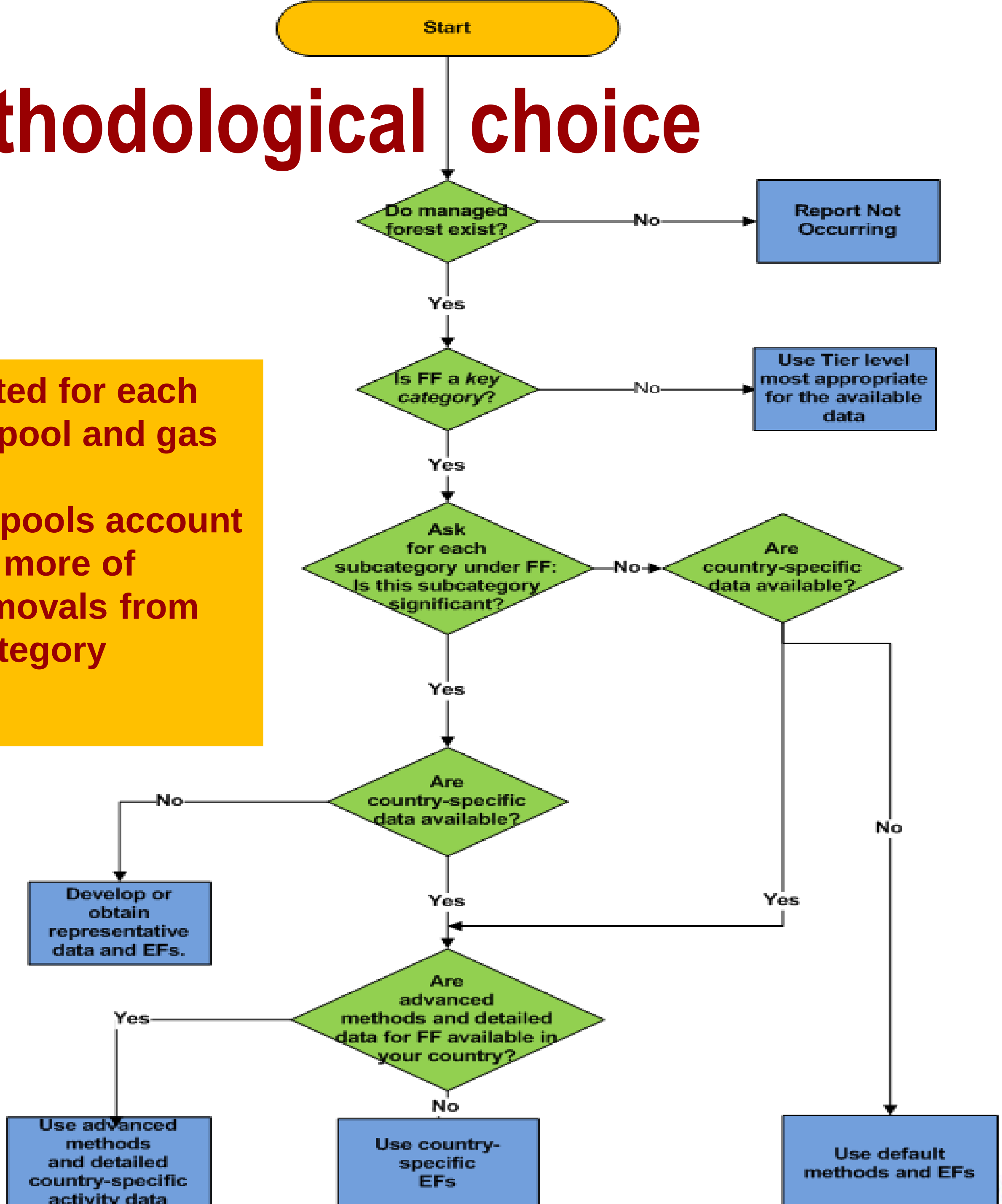
And the answer is…

Initial / Final	FL	CL	GL	WL	SE	OL	Final Area
FL	50	2	6	0	2	0	60
CL	5	35	8	0	2	0	50
GL	3	7	27	0	0	0	37
WL	8	0	0	20	3	0	31
SE	0	0	0	0	32	0	32
OL	0	0	0	0	0	5	5
Initial Area	66	44	41	20	39	5	215

Methodological choice

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



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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*), ΔC_G

$$\Delta C_G = \Sigma_{i,j} (A_{i,j} \, G_{TOTALi,j} \, CF_{i,j})$$

Where:

ΔC_G = 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 = area of land remaining in the same land-use category, ha
G_{TOTAL}= mean annual biomass growth, tonnes d. m. ha^{-1} yr^{-1}
i = ecological zone (*i* = 1 to *n*)
j = climate domain (*j* = 1 to *m)*
CF = carbon fraction of dry matter, tonne C (tonne d.m.)$^{-1}$

Average annual increment in biomass (G_{TOTAL}): Tier 1

$$G_{TOTAL} = \Sigma\{G_W \bullet (1 + R)\}$$

Where:

G_{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)$^{-1}$

Average annual increment in biomass (G_{TOTAL}): Tier 2 &3

$$G_{TOTAL} = \Sigma\{I_V \bullet BCEF_I \bullet (1+ R)\}$$

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

$BCEF_I$ = 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)$^{-1}$

BCEF = BEF_1.D (GPG LULUCF)

Biomass carbon stocks losses (*Gain-Loss Method*), ΔC_L

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

Where:

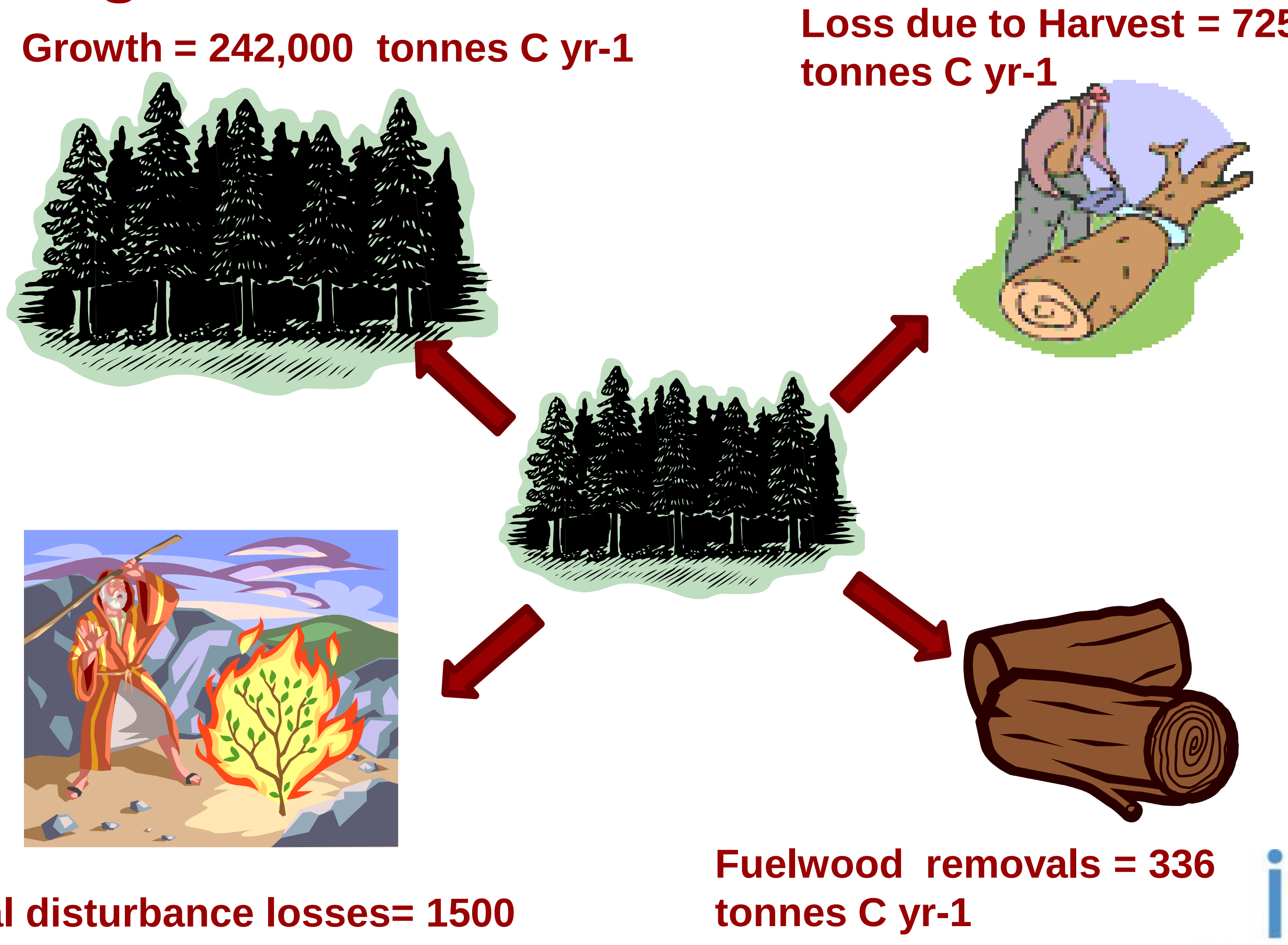
ΔC_L = annual decrease in carbon stocks due to biomass loss in land remaining in the same land-use category, tonnes C yr^{-1}

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

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

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

Ex. # 1: Can you find the biomass C pool loss/gain?



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And the answer is…

$\Delta C_G = 242{,}000$ tonnes C yr-1

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

$= 725 + 336 + 1500$

$= 2561$ tonnes C yr-1

$\Delta C_{biomass} = \Delta C_G - \Delta C_L$

$= 242{,}000 - 2561 = 239439$ tonnes C yr-1

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Stock Change Method

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

$$C = \Sigma_{ij} A_{ij} V_{ij} BCEF_S (1+R_{ij}) CF_{ij}$$

C = total carbon in biomass for time t_1 to t_2 [i = ecological zone i (i = 1 to n)

j = climate domain j (j = 1 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

Biomass: *Land Converted to Other Land-Use Category*

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

Where:

ΔC_B = annual change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr^{-1}

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

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

ΔC_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}

Initial change in biomass carbon stocks in *Land Converted to Other Land-Use Category*

$$\Delta C_{CONVERSION} = \Sigma_i (B_{AFTER} - B_{BEFORE}) \bullet \Delta A_{TO\ OTHERS\ i} \bullet CF$$

Where:

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

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

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

$\Delta A_{TO\_OTHERS\,i}$ = 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

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

$$\Delta C_{DOM} = [A \bullet (DOM_{in} - DOM_{out})] \bullet CFc$$

A = area of managed land,ha

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

DOM_{out} = average annual transfer out of DW/litter pool, t d.m./ha/yr

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

Stock-Difference Method

$$\Delta C_{DOM} = [A \bullet (DOM_{t2} - DOM_{t1})/T] \bullet CF$$

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.)

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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

$$\Delta C_{soils} = \Delta C_{Mineral} - L_{Organic} + \Delta C_{Inorganic}$$

Where:

ΔC_{Soils} = annual change in carbon stocks in soils, t C yr^{-1}

$\Delta C_{Mineral}$= annual change in organic carbon stocks in mineral soils, t C yr^{-1}

$L_{Organic}$ = annual loss of carbon from drained organic soils, t C yr^{-1}

$\Delta C_{Inorganic}$ = annual change in inorganic carbon stocks from soils, t C yr^{-1} (assumed to be 0 unless using a Tier 3 approach)

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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)

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

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

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.

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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)

$$\Delta C_{FFOrganic} = A_{Drained} \bullet EF_{Drainage}$$

Where:

$\Delta C_{FFOrganic}$ = CO_2 emissions from drained organic soils, t C/yr

$A_{drained}$ = Area of drained organic soils, ha

$EF_{Drainage}$ =EF for CO_2 from drained organic soils, t C/ha/yr

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

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.

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.

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 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.

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.).

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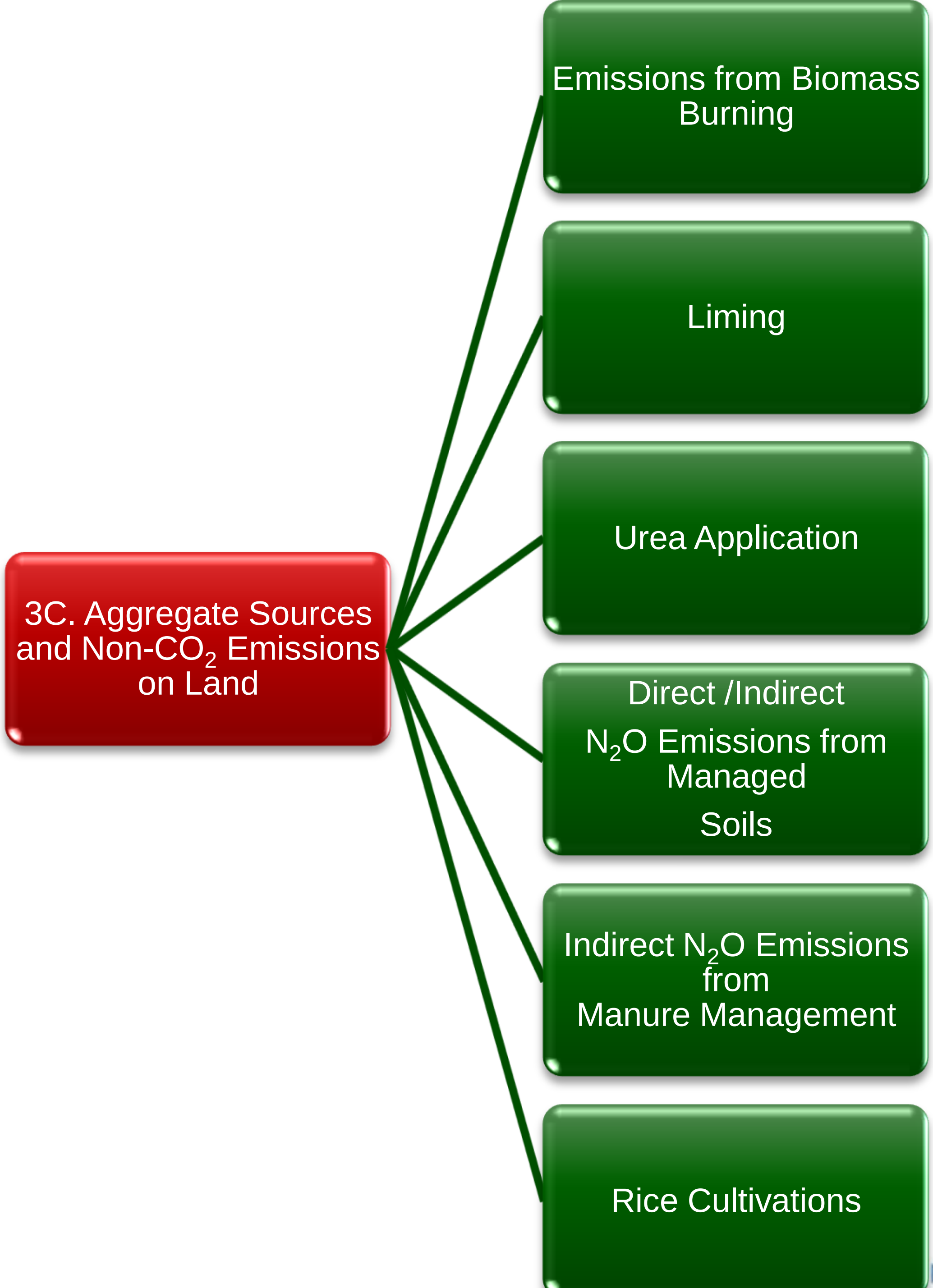
Reporting and Documentation

- 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.

3C. AGGREGATE SOURCES AND NON-CO2 EMISSIONS ON LAND


3C. Aggregate Sources and Non-CO_2 Emissions on Land
Emissions from Biomass Burning
Liming
Urea Application
Direct /Indirect N_2O Emissions from Managed Soils
Indirect N_2O 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_2O) and source category and an area (e.g., for soil or area burnt) that defines the emission

$$\textbf{\textit{Emission = A• EF}}$$

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_2O, $NO_{x.}$) species.
- Non-CO_2 greenhouse gas emissions are estimated for all land use categories.

Non-CO_2 emissions from biomass burning (2)

$$L_{fire} = A \bullet MB \bullet Cf \bullet Gef \bullet 10^{-3}$$

Where:

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

$$CO_2{-}C_{\ Emission} = = M.EF_{lime\ /urea}$$

Where,

M= annual amount of lime/urea applied ($ty r^{-1}$)

EF = emission factor(t CO_2-C/tonne of lime or urea)

Direct N_2O emissions from managed soils

- Nitrous oxide is produced naturally in soils through the processes of nitrification and denitrification.
- The emissions of N_2O 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 NH3 and NOx and subsequent redeposition, and through leaching and runoff)

Direct N_2O emissions from managed soils (2)

$$N_2O_{Direct}\text{–}N = N_2O\text{–}N_{N\,inputs} + N_2O\text{–}N_{OS} + N_2O\text{–}N_{PRP}$$

$$N_2O\text{–}N_{N\,inputs} = \left[\begin{array}{l} \left[\left(F_{SN} + F_{ON} + F_{CR} + F_{SOM} \right) \bullet EF_1 \right] + \\ \left[\left(F_{SN} + F_{ON} + F_{CR} + F_{SOM} \right)_{FR} \bullet EF_{1FR} \right] \end{array} \right]$$

$$N_2O\text{–}N_{OS} = \left(F_{OS,CG,Temp} \bullet EF_{2CG,Temp} \right) + \left(F_{OS,CG,Trop} \bullet EF_{2CG,Trop} \right)$$

$$N_2O\text{–}N_{PRP} = \left[\left(F_{PRP,CPP} \bullet EF_{3PRP,CPP} \right) + \left(F_{PRP,SO} \bullet EF_{3PRP,SO} \right) \right]$$

Where:

N_2O_{Direct} –N = annual direct N_2O–N emissions produced from agricultural soils, kg N_2O–N yr^{-1}

N_2O–$N_{Ninputs}$ = annual direct N2O–N emissions from N inputs to agricultural soils, kg N2O–N yr^{-1}

N_2O–N_{OS} = annual direct N_2O–N emissions from agricultural organic soils, kg N_2O–N yr^{-1}

N_2O–N_{PRP} = annual direct N_2O–N emissions from urine and dung inputs to grazed soils, kg N2O–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}

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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 N2O emissions from N inputs, kg N_2O–N (kg N input$)^{-1}$(Table 11.1)

EF_{1FR} is the emission factor for N2O emissions from N inputs to flooded rice, kg N_2O–N (kg N input$)^{-1}$ (Table 11.1) 5

EF_2 = emission factor for N2O 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 N2O–N (kg N input)-1; ((Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

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Indirect N_2O emissions from managed soils

- In addition to the direct emissions of N_2O from managed soils that occur through a direct pathway (i.e., directly from the soils to which N is applied), emissions of N_2O 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_2O)

$$N_2O_{(ATD)}\text{–}N = \left[\left(F_{SN} \bullet Frac_{GASF} \right) + \left(\left(F_{ON} + F_{PRP} \right) \bullet Frac_{GASM} \right) \right] \bullet EF_4$$

Where:

$N2O_{(ATD)–}N$ = annual amount of N_2O–N produced from atmospheric deposition of N volatilised from soils, kg N2O–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 NH3 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$)^{-1}$]

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Leaching/Runoff (N_2O)

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

Where:

$N2O_{(L)}$–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 N2O emissions from N leaching and runoff, kg N_2O–N (kg N leached and runoff)$^{-1}$

Leaching/Runoff (N_2O) (2)

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

Where:

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

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

$Frac_{GASFi}$ = 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_2O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N2O (kg NH_3–N + NOx–N volatilised$)^{-1}$]

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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

CH_4 emissions from rice (2)

CH4 emissions from rice cultivation are given by:

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

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 CH4 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

CH_4 emissions from rice (3)

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

Where:

EFi = adjusted daily emission factor for a particular harvested area

EFc = baseline emission factor for continuously flooded fields without organic amendments

SFw = scaling factor to account for the differences in water regime during the cultivation period

SFp = scaling factor to account for the differences in water regime in the pre-season before the cultivation period

SFo = scaling factor should vary for both type and amount of organic amendment applied

SFs,r = scaling factor for soil type, rice cultivar, etc., if available

Uncertainty assessment

- The main sources for uncertainty for AFOLU sector are:
  - Climate variability, and variability within units that are assumed to be homogenous, such as spatial variability in a field or soil unit.
  - Non representativeness of EFs and parameters (incl. accuracy of the livestock characterisation), and their correspondence with national circumstances
  - Accuracy and reliability of activity data
- In general use of higher tier methods with data corresponding more closely with the national circumstances will help reduce uncertainty.

Completeness

- To ensure completeness it is *good practice* to include:
  - all the major livestock categories and MMS in the country
  - 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.

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 forest inventories) and methods using time-series consistent methods.
- Some ways of ensuring time series consistency in LULUCF are:
  - collection of an internally consistent time series of livestock population
  - keeping track of the land transitions through a Land-use Change Matrix
  - 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.

Thank you !!
Any Questions?

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