

# **CHAPTER 1**

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## **INTRODUCTION**

## **Authors**

Keith Paustian (USA), N.H. Ravindranath (India), and Andre van Amstel (Netherlands)

Michael Gytarsky (Russian Federation), Werner A. Kurz (Canada), Stephen Ogle (USA), Gary Richards (Australia), and Zoltan Somogyi (European Commission/Hungary)

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## 1.1 INTRODUCTION

Volume 4 provides guidance for preparing annual greenhouse gas inventories in the Agriculture, Forestry and Other Land Use (AFOLU) Sector. This volume integrates the previously separate guidance in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* for Agriculture (Chapter 4) and Land Use, Land-Use Change and Forestry (Chapter 5). This integration recognizes that the processes underlying greenhouse gas emissions and removals, as well as the different forms of terrestrial carbon stocks, can occur across all types of land. It recognizes that land-use changes can involve all types of land. This approach is intended to improve consistency and completeness in the estimation and reporting of greenhouse gas emissions and removals.

The principal changes made in the *2006 IPCC Guidelines*, as compared with the *1996 IPCC Guidelines* (for both Land-Use Change and Forestry, and Agriculture), reflect the elaborations of the *1996 IPCC Guidelines* introduced in the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (*GPG2000*) and the Good Practice Guidance for Land Use, Land-Use Change and Forestry (*GPG-LULUCF*). These include:

- Adoption of the six land-use categories used in *GPG-LULUCF* (i.e., Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land – see Chapter 3). These land categories are further sub-divided into land remaining in the same category and land converted from one category to another. The land-use categories are designed to enable inclusion of all managed land area within a country;
- Reporting on all emissions by sources and removals by sinks from managed lands, which are considered to be anthropogenic, while emissions and removals for unmanaged lands are not reported.
- Additional reporting elements introduced in reporting all emissions and removals for managed lands, (see Table 1.2).
- Generic methods for accounting of biomass, dead organic matter and soil C stock changes in all land-use categories and generic methods for greenhouse gas emissions from biomass burning that can be applied in all land-use categories;
- Incorporating methods for non-CO<sub>2</sub> emissions from managed soils and biomass burning, and livestock population characterization and manure management systems from Agriculture (Chapter 5 of the *1996 IPCC Guidelines* and *GPG2000*);
- Adoption of three hierarchical tiers of methods that range from default emission factors and simple equations to the use of country-specific data and models to accommodate national circumstances;
- Description of alternative methods to estimate and report C stock changes associated with harvested wood products;
- Incorporation of key category analysis for land-use categories, C pools, and CO<sub>2</sub> and non-CO<sub>2</sub> greenhouse gas emissions;
- Adherence to principles of mass balance in computing carbon stock changes;
- Greater consistency in land area classification for selecting appropriate emission and stock change factors and activity data;
- Improvements of default emissions and stock change factors, as well as development of an Emission Factor Database (EFDB) that is a supplementary tool to the *2006 IPCC Guidelines*, providing alternative emission factors with associated documentation. The EFDB is described in Chapter 2 of Volume 1.
- Incorporation of methods to estimate CO<sub>2</sub> emissions from flooded land with methods for CH<sub>4</sub> emissions contained in Appendix 3 (CH<sub>4</sub> Emissions from Flooded Land: Basis for future methodological development), reflecting the limited availability of scientific information.

The AFOLU Sector has some unique characteristics with respect to developing inventory methods. There are many processes leading to emissions and removals of greenhouse gases, which can be widely dispersed in space and highly variable in time. The factors governing emissions and removals can be both natural and anthropogenic (direct and indirect) and it can be difficult to clearly distinguish between causal factors<sup>1</sup>. While

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<sup>1</sup> This general observation was made in the IPCC Report on *Current Scientific Understanding of the Processes Affecting Terrestrial Carbon Stocks and Human Influences upon Them* (July 2003, Geneva, Switzerland). As a specific example, emissions from wildfires on managed (and unmanaged) land can exhibit large interannual variations that may be driven by either natural causes (e.g. climate cycles, random variation in lightning ignitions), or indirect and direct human causes (e.g.

recognizing this complexity, inventory methods need to be practical and operational. The *2006 IPCC Guidelines* are designed to assist in estimating and reporting national inventories of anthropogenic greenhouse gas emissions and removals. For the AFOLU Sector, anthropogenic greenhouse gas emissions and removals by sinks are defined as all those occurring on ‘managed land’. **Managed land is land where human interventions and practices have been applied to perform production, ecological or social functions.** All land definitions and classifications should be specified at the national level, described in a transparent manner, and be applied consistently over time. Emissions/removals of greenhouse gases do not need to be reported for unmanaged land. However, it is *good practice* for countries to quantify, and track over time, the area of unmanaged land so that consistency in area accounting is maintained as land-use change occurs.

This approach, i.e., the use of managed land as a proxy for anthropogenic effects, was adopted in the GPG-LULUCF and that use is maintained in the present guidelines. The key rationale for this approach is that the preponderance of anthropogenic effects occurs on managed lands. By definition, all direct human-induced effects on greenhouse gas emissions and removals occur on managed lands only. While it is recognized that no area of the Earth’s surface is entirely free of human influence (e.g., CO<sub>2</sub> fertilization), many indirect human influences on greenhouse gases (e.g., increased N deposition, accidental fire) will be manifested predominately on managed lands, where human activities are concentrated. Finally, while local and short-term variability in emissions and removals due to natural causes can be substantial (e.g., emissions from fire, see footnote 1), the natural ‘background’ of greenhouse gas emissions and removals by sinks tends to average out over time and space. This leaves the greenhouse gas emissions and removals from managed lands as the dominant result of human activity.

Guidance and methods for estimating greenhouse gas emissions and removals for the AFOLU Sector now include:

- CO<sub>2</sub> emissions and removals resulting from C stock changes in biomass, dead organic matter and mineral soils, for all managed lands;
- CO<sub>2</sub> and non-CO<sub>2</sub> emissions from fire on all managed land;
- N<sub>2</sub>O emissions from all managed soils;
- CO<sub>2</sub> emissions associated with liming and urea application to managed soils;
- CH<sub>4</sub> emissions from rice cultivation;
- CO<sub>2</sub> and N<sub>2</sub>O emissions from cultivated organic soils;
- CO<sub>2</sub> and N<sub>2</sub>O emissions from managed wetlands (with a basis for methodological development for CH<sub>4</sub> emissions from flooded land in an Appendix 3);
- CH<sub>4</sub> emission from livestock (enteric fermentation);
- CH<sub>4</sub> and N<sub>2</sub>O emissions from manure management systems; and
- C stock change associated with harvested wood products.

The scientific background and rationale for these inventory components are given in the next section.

## 1.2 OVERVIEW OF GREENHOUSE GAS EMISSIONS AND REMOVALS IN THE AFOLU SECTOR

### 1.2.1 Science background

Land use and management influence a variety of ecosystem processes that affect greenhouse gas fluxes (Figure 1.1), such as photosynthesis, respiration, decomposition, nitrification/denitrification, enteric fermentation, and combustion. These processes involve transformations of carbon and nitrogen that are driven by the biological (activity of microorganisms, plants, and animals) and physical processes (combustion, leaching, and run-off).

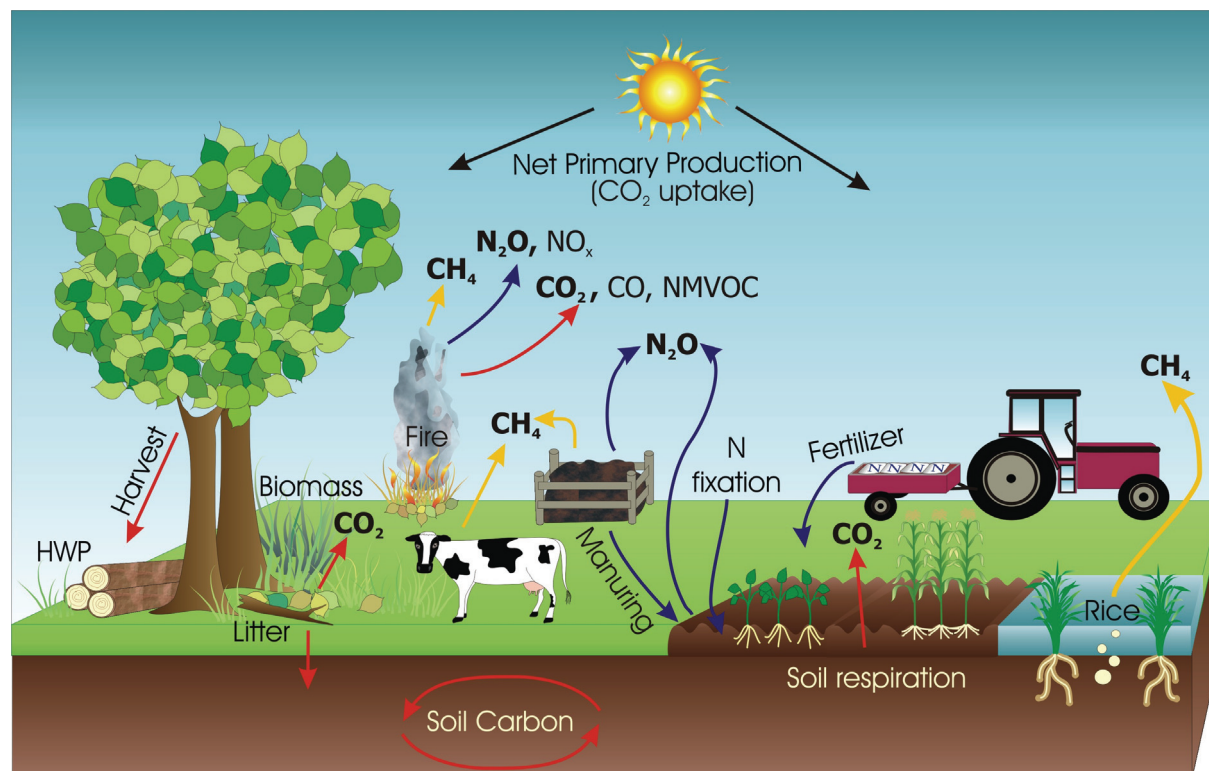
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historical fire suppression and past forest harvest activities) or a combination of all three causes, the effects of which cannot be readily separated.

## Greenhouse Gases in AFOLU

The key greenhouse gases of concern are  $\text{CO}_2$ ,  $\text{N}_2\text{O}$  and  $\text{CH}_4$ .  $\text{CO}_2$  fluxes between the atmosphere and ecosystems are primarily controlled by uptake through plant photosynthesis and releases via respiration, decomposition and combustion of organic matter.  $\text{N}_2\text{O}$  is primarily emitted from ecosystems as a by-product of nitrification and denitrification, while  $\text{CH}_4$  is emitted through methanogenesis under anaerobic conditions in soils and manure storage, through enteric fermentation, and during incomplete combustion while burning organic matter. Other gases of interest (from combustion and from soils) are  $\text{NO}_x$ ,  $\text{NH}_3$ , NMVOC and  $\text{CO}$ , because they are precursors for the formation of greenhouse gases in the atmosphere. Formation of greenhouse gases from precursor gases is considered an indirect emission. Indirect emissions are also associated with leaching or run-off of nitrogen compounds, particularly  $\text{NO}_3^-$  losses from soils, some of which can be subsequently converted to  $\text{N}_2\text{O}$  through denitrification.

**Figure 1.1** The main greenhouse gas emission sources/removals and processes in managed ecosystems.



## Emission and Removal Processes

Greenhouse gas fluxes in the AFOLU Sector can be estimated in two ways: 1) as net changes in C stocks over time (used for most  $\text{CO}_2$  fluxes) and 2) directly as gas flux rates to and from the atmosphere (used for estimating non- $\text{CO}_2$  emissions and some  $\text{CO}_2$  emissions and removals). The use of C stock changes to estimate  $\text{CO}_2$  emissions and removals, is based on the fact that changes in ecosystem C stocks are predominately (but not exclusively) through  $\text{CO}_2$  exchange between the land surface and the atmosphere (i.e. other C transfer process such as leaching are assumed to be negligible). Hence, increases in total C stocks over time are equated with a net removal of  $\text{CO}_2$  from the atmosphere and decreases in total C stocks (less transfers to other pools such as harvested wood products) are equated with net emission of  $\text{CO}_2$ . Non- $\text{CO}_2$  emissions are largely a product of microbiological processes (i.e., within soils, animal digestive tracts and manure) and combustion of organic materials. Below, emission and removal processes in the AFOLU Sector are described for the major ecosystem stocks and processes, organized by ecosystem components, i.e., 1) biomass, 2) dead organic matter, 3) soils and 4) livestock.

### Biomass

Plant biomass, including above-ground and below-ground parts, is the main conduit for  $\text{CO}_2$  removal from the atmosphere. Large amounts of  $\text{CO}_2$  are transferred between the atmosphere and terrestrial ecosystems, primarily through photosynthesis and respiration. The uptake of  $\text{CO}_2$  through photosynthesis is referred to as gross primary production (GPP). About half of the GPP is respired by plants, and returned to the atmosphere, with the remainder constituting net primary production (NPP), which is the total production of biomass and dead organic

matter in a year. NPP minus losses from heterotrophic respiration (decomposition of organic matter in litter, dead wood and soils) is equal to the net carbon stock change in an ecosystem and, in the absence of disturbance losses, is referred to as net ecosystem production (NEP).

$$\text{Net Ecosystem Production (NEP)} = \text{Net Primary Production (NPP)} - \text{Heterotrophic respiration}$$

NEP minus additional C losses from disturbance (e.g., fire), harvesting and land clearing during land-use change, is often referred to as net biome production (NBP). The carbon stock change that is reported in national greenhouse gas inventories for land-use categories is equal to NBP<sup>2</sup>.

$$\text{Net Biome Production (NBP)} = \text{NEP} - \text{Carbon Losses from Disturbance/Land-Clearing/Harvest}$$

NPP is influenced by land use and management through a variety of anthropogenic actions such as deforestation, afforestation, fertilization, irrigation, harvest, and species choice. For example, tree harvesting reduces biomass stocks on the land. However, harvested wood requires additional consideration because some of the carbon may be stored in wood products in use and in landfills for years to centuries. Thus, some of the carbon removed from the ecosystem is rapidly emitted to the atmosphere while some carbon is transferred to other stocks in which the emissions are delayed. In non-forest ecosystems (i.e., Cropland, Grassland), biomass is predominantly non-woody perennial and annual vegetation, which makes up a much smaller part of total ecosystem carbon stocks than in forest lands. The non-woody biomass turns over annually or within a few years and hence net biomass carbon stocks may remain roughly constant, although stocks may diminish over time if land degradation is occurring. Land managers may use fire as a management tool in grasslands and forests or wild fires may inadvertently burn through managed lands, particularly forest lands, leading to significant losses of biomass carbon. Fires not only return CO<sub>2</sub> to the atmosphere through combustion of biomass, but also emit other greenhouse gases, directly or indirectly, including CH<sub>4</sub>, N<sub>2</sub>O, NMVOC, NO<sub>x</sub> and CO.

### ***Dead Organic Matter***

The bulk of biomass production (NPP) contained in living plant material is eventually transferred to dead organic matter (DOM) pools (i.e., dead wood and litter – see Table 1.1 for definitions). Some DOM decomposes quickly, returning carbon to the atmosphere, but a portion is retained for months to years to decades. Land use and management influence C stocks of dead organic matter by affecting the decomposition rates and input of fresh detritus. Losses due to burning dead organic matter include emissions of CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, NO<sub>x</sub>, NMVOC, and CO.

### ***Soils***

As dead organic matter is fragmented and decomposed, it is transformed into soil organic matter (SOM). Soil organic matter includes a wide variety of materials that differ greatly in their residence time in soil. Some of this material is composed of labile compounds that are easily decomposed by microbial organisms, returning carbon to the atmosphere. Some of the soil organic carbon, however, is converted into recalcitrant compounds (e.g., organic-mineral complexes) that are very slowly decomposed and thus can be retained in the soil for decades to centuries or more. Following fires, small amounts of so-called ‘black carbon’ are produced, which constitute a nearly inert carbon fraction with turnover times that may span millennia.

Soil organic carbon stocks are influenced by land-use and management activities that affect litter input rates and soil organic matter loss rates. Although the dominant processes governing the balance of soil organic carbon stocks are C inputs from plant residues and C emissions from decomposition, losses as particulate or dissolved carbon can be significant in some ecosystems. Inputs are primarily controlled by decisions impacting NPP and/or the retention of dead organic matter, such as how much harvested biomass is removed as products and how much is left as residues. Outputs are mostly influenced by management decisions that affect microbial and physical decomposition of soil organic matter, such as tillage intensity. Depending on interactions with previous land use, climate and soil properties, changes in management practices may induce increases or decreases in soil C stocks. Generally, management-induced C stock changes are manifested over a period of several years to a few decades, until soil C stocks approach a new equilibrium. In addition to the influence of human activities, climate variability and other environmental factors affect soil C dynamics (as well as biomass and DOM).

In flooded conditions, such as wetland environments and paddy rice production, a significant fraction of the decomposing dead organic matter and soil organic matter is returned to the atmosphere as CH<sub>4</sub>. This can be a

<sup>2</sup> Harvested wood or other durable products derived from biomass (e.g., clothing) products are not included in NBP; harvested wood products (HWP) are dealt with in Chapter 12.



major source of emissions in countries with a considerable amount of land dedicated to paddy rice production. Although virtually all flooded soils emit methane, net soil C stocks may either increase, decrease or remain constant over time, depending on management and environmental controls on the overall carbon balance. In well-drained soils, small amounts of CH<sub>4</sub> are consumed (oxidized) by methanotrophic bacteria.<sup>3</sup>

Soils also contain inorganic C pools, either as primary minerals in the parent material from which the soil was formed (e.g., limestone), or as secondary minerals (i.e., pedogenic carbonates) that arise during soil formation. Inorganic soil C stocks can be affected by management, although typically not to the extent of organic C pools.

Some soil management practices impact greenhouse gas emissions beyond simply changing the C stock. For example, liming is used to reduce soil acidity and improve plant productivity, but it is also a direct source of CO<sub>2</sub> emissions. Specifically, liming transfers C from the earth's crust to the atmosphere by removing calcium carbonate from limestone and dolomite deposits and applying it to soils where the carbonate ion evolves into CO<sub>2</sub>.

Nitrogen additions are a common practice for increasing NPP and crop yields, including application of synthetic N fertilizers and organic amendments (e.g., manure), particularly to Cropland and Grassland. This increase in soil N availability increases N<sub>2</sub>O emissions from soils as a by-product of nitrification and denitrification. Nitrogen additions (in dung and urine) by grazing animals can also stimulate N<sub>2</sub>O emissions. Similarly, land-use change enhances N<sub>2</sub>O emissions if associated with heightened decomposition of soil organic matter and subsequent N mineralization, such as initiating cultivation on wetlands, forests or grasslands.

With current state of scientific knowledge, it is possible to provide methods for estimating CO<sub>2</sub> and N<sub>2</sub>O emissions associated with management of peatlands, and CO<sub>2</sub> from conversion to wetlands by flooding. A methodological appendix (Appendix 3) has been included setting out a basis for development of a methodology for estimating CH<sub>4</sub> emissions from flooded land.

### ***Livestock***

Animal production systems, particularly those with ruminant animals, can be significant sources of greenhouse gas emissions. For example, enteric fermentation in the digestive systems of ruminants leads to production and emission of CH<sub>4</sub>. Management decisions about manure disposal and storage affect emissions of CH<sub>4</sub> and N<sub>2</sub>O, which are formed in decomposing manures as a by-product of methanogenesis and nitrification/denitrification, respectively. Furthermore, volatilization losses of NH<sub>3</sub> and NO<sub>x</sub> from manure management systems and soils leads to indirect greenhouse gas emissions.

## **1.2.2 Carbon pool definitions and non-CO<sub>2</sub> gases**

Within each land-use category, C stock changes and emission/removal estimations can involve the five carbon pools that are defined in Table 1.1. For some land-use categories and estimation methods, C stock changes may be based on the three aggregate carbon pools (i.e., biomass, DOM and soils). National circumstances may require modifications of the pool definitions introduced here. Where modified definitions are used, it is *good practice* to report and document them clearly, to ensure that modified definitions are used consistently over time, and to demonstrate that pools are neither omitted nor double counted. Carbon stock changes associated with harvested wood products are normally reported at the national scale (see Chapter 12).

The non-CO<sub>2</sub> gases of primary concern for the AFOLU Sector are methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). Emissions of other nitrogenous gases including NO<sub>x</sub> and NH<sub>3</sub>, which can serve as a source of subsequent N<sub>2</sub>O emissions (and hence referred to as *indirect* emission sources), are also considered (see Chapter 11).

## **1.3 OVERVIEW OF INVENTORY PREPARATION FOR THE AFOLU SECTOR**

To prepare inventories for the AFOLU Sector, emissions and removals of CO<sub>2</sub> and non-CO<sub>2</sub> greenhouse gases are estimated separately for each of six land-use categories. Other CO<sub>2</sub> emission and non-CO<sub>2</sub> categories, such as livestock related emissions, emissions from soil N management, soil liming emissions and harvested wood products, may be estimated at the national scale, since often only aggregate data are available. However, they can be broken out according to land-use category if data are available.

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<sup>3</sup> Disturbance through land-use change and addition of nitrogen (i.e., as fertilizer) have been found to reduce rates of methane oxidation.



**TABLE 1.1**  
**DEFINITIONS FOR CARBON POOLS USED IN AFOLU FOR EACH LAND-USE CATEGORY**

| Pool  |                                  | Description  |
|---|----------------------------------|--|
| <b>Biomass</b>  | Above-ground biomass             | All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage.<br><br>Note: In cases where forest understory is a relatively small component of the above-ground biomass carbon pool, it is acceptable for the methodologies and associated data used in some tiers to exclude it, provided the tiers are used in a consistent manner throughout the inventory time series.  |
|   | Below-ground biomass             | All biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.   |
| <b>Dead organic matter</b>  | Dead wood                        | Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter (or the diameter specified by the country).   |
|   | Litter                           | Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g. 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically. |
| <b>Soils</b>  | Soil organic matter <sup>1</sup> | Includes organic carbon in mineral soils to a specified depth chosen by the country and applied consistently through the time series <sup>2</sup> . Live and dead fine roots and DOM within the soil, that are less than the minimum diameter limit (suggested 2 mm) for roots and DOM, are included with soil organic matter where they cannot be distinguished from it empirically. The default for soil depth is 30 cm and guidance on determining country-specific depths is given in Chapter 2.3.3.1.   |
| <sup>1</sup> Includes organic material (living and non-living) within the soil matrix, operationally defined as a specific size fraction (e.g., all matter passing through a 2 mm sieve). Soil C stock estimates may also include soil inorganic C if using a Tier 3 method. CO <sub>2</sub> emissions from liming and urea applications to soils are estimated as fluxes using Tier 1 or Tier 2 method.<br><sup>2</sup> Carbon stocks in organic soils are not explicitly computed using Tier 1 or Tier 2 method, (which estimate only annual C flux from organic soils), but C stocks in organic soils can be estimated in a Tier 3 method. Definition of organic soils for classification purposes is provided in Chapter 3. |                                  |  |

### 1.3.1 Land-use and management categories

A brief overview of how land area is categorized for inventory purposes is given here. Chapter 3 provides a detailed description of land representation and categorization of land area by land-use and management systems as well as stratification of land area by climate, soil and other environmental strata.

The six land-use categories (see definitions in Chapter 3) in the *2006 IPCC Guidelines* are:

- Forest Land
- Cropland
- Grassland
- Wetlands
- Settlements
- Other Land

Each land-use category is further subdivided into land remaining in that category (e.g., *Forest Land Remaining Forest Land*) and land converted from one category to another (e.g., *Forest Land converted to Cropland*). Countries may choose to further stratify land in each category by climatic or other ecological regions, depending on the choice of the method and its requirements. Greenhouse gas emissions and removals determined for each specific land use includes CO<sub>2</sub> (as carbon stock changes) from biomass, dead organic matter and soils, as well as

non-CO<sub>2</sub> emissions from burning and, depending on the land-use category, emissions from other specific sources (e.g. CH<sub>4</sub> emissions from rice).

CH<sub>4</sub> and N<sub>2</sub>O emissions from livestock management are estimated for major animal types, e.g., dairy cows, other cattle, poultry, sheep, swine and other livestock (buffalo, goats, llamas, alpacas, camels, etc). The animal waste management systems include anaerobic lagoons, liquid systems, daily spread, solid storage, dry-lot, pasture/range/paddock, and other miscellaneous systems.

Nitrous oxide emissions from managed soils are usually estimated from aggregate (national-level) data on N supplied to soils, including N fertilizer usage or sales, crop residue management, organic amendments and land-use conversions that enhance mineralization of N in soil organic matter. Similarly, CO<sub>2</sub> emissions from liming and from urea application to managed soils are typically estimated using aggregate data (e.g., national-level).<sup>4</sup>

Harvested wood products constitute a component of the carbon cycle for which carbon stock changes can be estimated (guidance provided in Chapter 12), based on national-level data; however, estimation and reporting of greenhouse gas emissions for HWP is currently a matter of policy negotiations.

### 1.3.2 Tier definitions for methods in AFOLU

The concepts underpinning the three tiered approach, as they relate to methods used in the AFOLU Sector, are outlined here (see Box 1.1). In general, moving to higher tiers improves the accuracy of the inventory and reduces uncertainty, but the complexity and resources required for conducting inventories also increases for higher tiers. If needed, a combination of tiers can be used, e.g., Tier 2 can be used for biomass and Tier 1 for soil carbon.

The methods and data presented focus on Tier 1 inventories. The methods will be generally applicable to Tier 2 inventories, but the default data presented for Tier 1 will be partly or wholly replaced with national data as part of a Tier 2 estimation. Tier 3 methods are not described in detail, but *good practice* in application is outlined.

### 1.3.3 Identification of key categories

The background discussion on the approach and methods for key category analysis are given in Volume 1 Chapter 4 (Methodological Choice and Identification of Key Categories). This chapter describes the approach to key category analysis for AFOLU. A key source/sink category is defined in Volume 1 Chapter 4 as *one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals*. Key category analysis helps a country to achieve the most reliable inventory given the resources available. Key category analysis is required to identify the following:

- which land-use and management activities are significant;
- which land-use or livestock (sub)category is significant;
- which CO<sub>2</sub> emissions or removals by sinks from various carbon pools are significant;
- which non-CO<sub>2</sub> gases and from what categories are significant; and
- which tier is required for reporting.

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<sup>4</sup> No default methodology exists for estimation of CH<sub>4</sub> removals in aerobic soils because of limited studies addressing land-use and management impacts on methane oxidation. Countries that wish to estimate and report CH<sub>4</sub> removals should develop, validate and document an appropriate national methodology for estimating CH<sub>4</sub> removals, including analysis of uncertainty. It is good practice for countries reporting CH<sub>4</sub> removals to also ensure symmetry by including all emissions of CH<sub>4</sub> on lands where CH<sub>4</sub> removals are reported.

### BOX 1.1

#### FRAMEWORK OF TIER STRUCTURE FOR AFOLU METHODS

**Tier 1** methods are designed to be the simplest to use, for which equations and default parameter values (e.g., emission and stock change factors) are provided in this volume. Country-specific activity data are needed, but for Tier 1 there are often globally available sources of activity data estimates (e.g., deforestation rates, agricultural production statistics, global land cover maps, fertilizer use, livestock population data, etc.), although these data are usually spatially coarse.

**Tier 2** can use the same methodological approach as Tier 1 but applies emission and stock change factors that are based on country- or region-specific data, for the most important land-use or livestock categories. Country-defined emission factors are more appropriate for the climatic regions, land-use systems and livestock categories in that country. Higher temporal and spatial resolution and more disaggregated activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialized land-use or livestock categories.

At **Tier 3**, higher order methods are used, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national level. These higher order methods provide estimates of greater certainty than lower tiers. Such systems may include comprehensive field sampling repeated at regular time intervals and/or GIS-based systems of age, class/production data, soils data, and land-use and management activity data, integrating several types of monitoring. Pieces of land where a land-use change occurs can usually be tracked over time, at least statistically. In most cases these systems have a climate dependency, and thus provide source estimates with interannual variability. Detailed disaggregation of livestock population according to animal type, age, body weight etc., can be used. Models should undergo quality checks, audits, and validations and be thoroughly documented.

The following chapters provide methodologies covering a broad array of source/sink categories in AFOLU. Not all categories are expected to be key and hence simple default methods (Tier 1) are provided to enable a complete inventory of AFOLU without requiring large investments of resources in relatively minor categories.

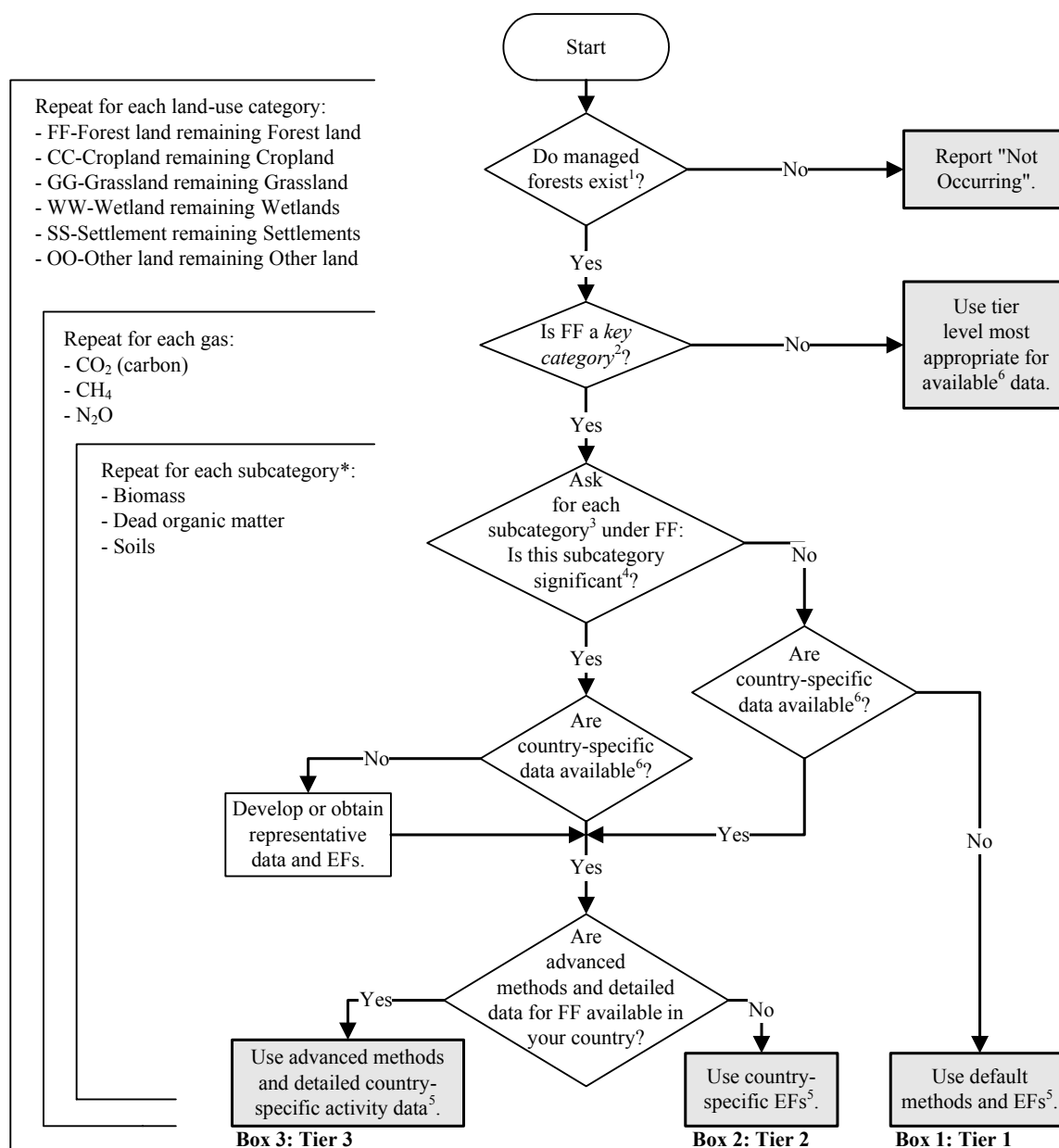
The analysis should be performed at the level of IPCC source or sink categories as suggested in Table 4.1 of Volume 1. The analysis should be performed using CO<sub>2</sub>-equivalent emissions estimated using the global warming potentials for each gas. The key category evaluation should be performed for each of these gases separately because the methods, emission factors and related uncertainties differ for each gas, pool and category. Source categories that use the same emission factors based on common assumptions should be aggregated before analysis. For each *key category*, the inventory agency should determine if certain sub-categories represent a significant share of the emissions. In the case of CH<sub>4</sub> emissions from enteric fermentation in domestic livestock, for example, emissions from particular species (e.g., cattle, buffalo or sheep) are likely to represent the major share of emissions (GPG2000, Chapter 7). In the case of CO<sub>2</sub> emissions/removals, a certain land category (e.g., *Land Converted to Forest Land*) and further a certain carbon pool (e.g., above-ground biomass) may contribute to a dominant share of net CO<sub>2</sub> emissions/removals.

The level of aggregation or disaggregation of different land-use (see Chapter 3) and livestock categories (see Chapter 10) depends on the share of a given land-use or livestock system within a country's greenhouse gas inventory and on the level of resources available in the country for inventory activities. Disaggregation of land and livestock categories helps in reducing the uncertainty; however it increases the cost of the inventory process. Thus, there is a need for balance between level of disaggregation and the resources available for inventory.

Once identified, the key sources are used for methodological choice via decision trees as shown below. Those for the AFOLU include:

- decision tree for identification of appropriate tier level for land remaining in the same land-use category (Figure 1.2), for e.g., *Forest Land Remaining Forest Land*;
- decision tree for identification of appropriate tier level for land converted to another land-use category (Figure 1.3), for e.g., other *Land Converted to Forest Land*; and
- decision trees for enteric fermentation and manure management which are provided in the relevant sectoral chapter (see Chapter 10).

**Figure 1.2** Decision tree for identification of appropriate tier level for land remaining in the same land-use category, using Forest Land Remaining Forest Land as an example.



Note:

1: The use of 20 years, as a threshold, is consistent with the defaults contained in IPCC Guidelines. Countries may use different periods where appropriate to national circumstances (see Chapter 2).

2: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

3: See Table 1.2 for the characterisation of subcategories.

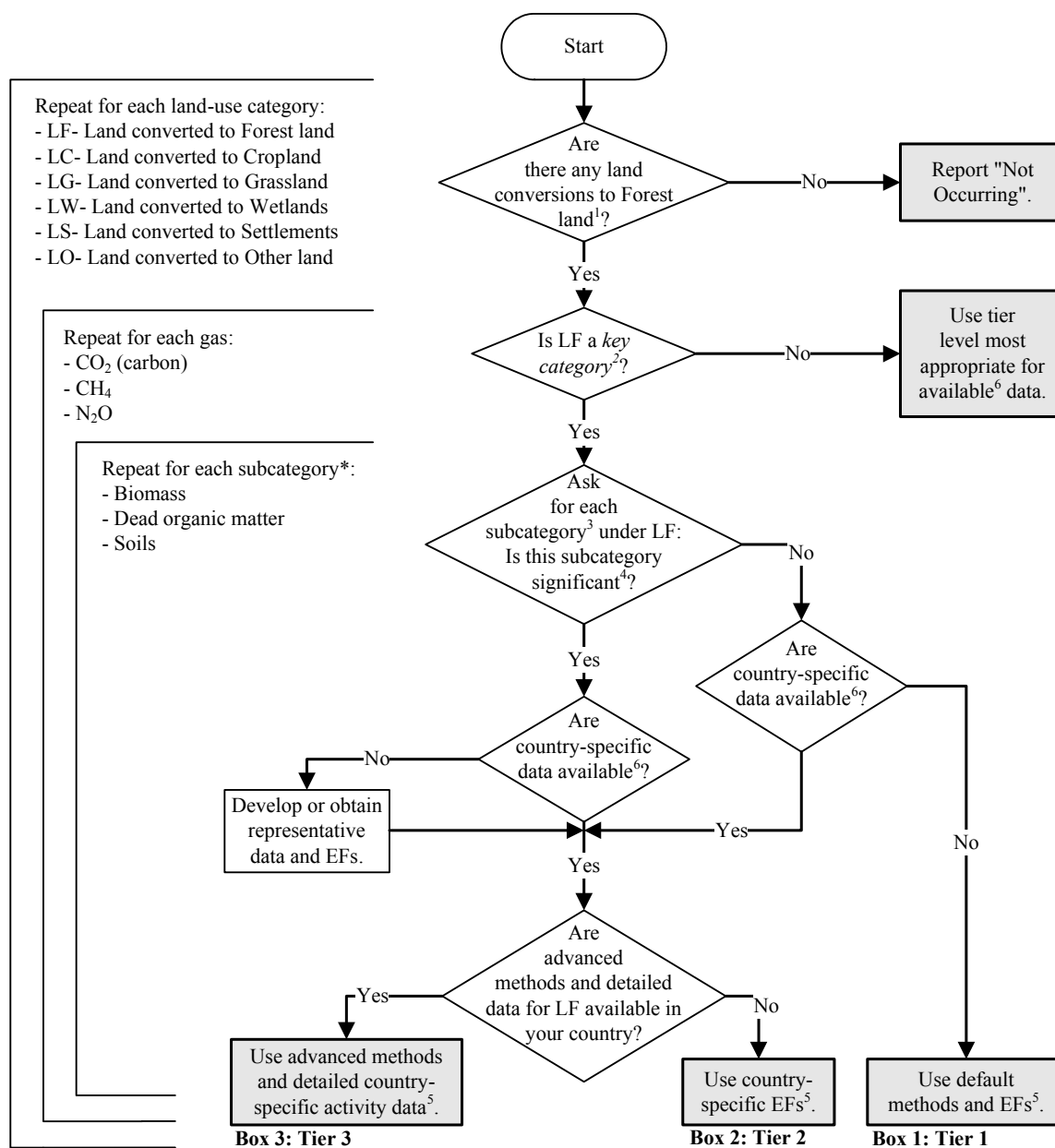
4: A subcategory is significant if it accounts for 25-30% of emissions/removals for the overall category.

5: See Box 1.1 for definition of Tier levels.

6: Data availability refers to both data needed for developing country-specific emission factors and data on land use and management practices (activity data).

\* If a country reports harvested wood products (HWP) as a separate pool, it should be treated as a subcategory.

**Figure 1.3** Decision tree for identification of appropriate Tier level for land converted to another land-use category, using Land Converted to Forest Land as an example.



Note:

1: The use of 20 years, as a threshold, is consistent with the defaults contained in IPCC Guidelines. Countries may use different periods where appropriate to national circumstances (see Chapter 2).

2: See Volume 1 Chapter 4, "Methodological Choice and Identification of Key Categories" (noting section 4.1.2 on limited resources), for discussion of *key categories* and use of decision trees.

3: See Table 1.2 for the characterisation of subcategories.

4: A subcategory is significant if it accounts for 25-30% of emissions/removals for the overall category.

5: See Box 1.1 for definition of Tier levels.

6: Data availability refers to both data needed for developing country-specific emission factors and data on land use and management practices (activity data)

\* If a country reports harvested wood products (HWP) as a separate pool, it should be treated as a subcategory.

### 1.3.4 Steps in preparing inventory estimates

The following steps describe the compilation of the greenhouse gas inventory for the AFOLU Sector:

1. Divide all land into managed and unmanaged (Chapter 3).
2. Develop a national land classification system applicable to all six land-use categories (Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land) and further subdivide by climate, soil type and/or ecological regions (i.e., strata) appropriate for the country, as described in Chapter 3.
3. Compile data on the area of land and the change in area of land in each land-use category (by category) if available. Categorize land area by specific management systems defined for each land-use category (by category), if available -this categorization provides the basis for assigning emission factors and stock change factors, required for a particular estimation approach (see Chapter 3).
4. Compile national-level statistics for livestock, manure management systems, soil N management, liming and urea application (if land-use specific activity data are available for soil fertilization and liming activities, these emissions categories can be stratified as in Step 2).
5. Estimate CO<sub>2</sub> emissions and removals and non-CO<sub>2</sub> emissions at the appropriate tier level in support of a key category analysis. A preliminary inventory is likely to utilize a Tier 1 or Tier 2 approach. However, it may be preferable to proceed with a Tier 3 approach if the methods have been previously developed and the supporting activity and input data have been compiled (see Chapter 2 for general guidance on methods).
6. Re-estimate CO<sub>2</sub> emissions and removals and non-CO<sub>2</sub> emissions if a higher Tier is recommended, based on the key category analysis (see Volume 1 Chapter 4 for methods to identify Key Categories).
7. Estimate uncertainties (see Volume 1 Chapter 3) and complete QA/QC procedures (which are initiated at Step 1) using the methods provided in Volume 1 Chapter 6, along with additional guidance provided in Chapters 2 to 12 of this Volume.
8. Sum CO<sub>2</sub> emissions and removals and non-CO<sub>2</sub> emissions over the inventory period for each source category by land use and stratum, as well as emissions from livestock, manure, and N management (if not analyzed separately for each land-use category).
9. Transcribe summary information into reporting tables, converting C stock changes to emissions or removals of CO<sub>2</sub> and entering non-CO<sub>2</sub> greenhouse gas emissions, by land-use categories, if available. Combine with any emission estimates that are based on national aggregate data (e.g. livestock, manure management and soil management/amendment) to estimate the total emissions and removals for the AFOLU Sector (See Volume 1 Chapter 8, Reporting Guidance and Tables).
10. Document and archive all information used to produce an inventory, including activity and other input data, emission factors, sources of data and metadata documentation, methods descriptions and model software or code, QA/QC procedures and reports, in addition to the results for each source category.
11. Set priorities for future inventories in AFOLU Sector based on completeness of current inventories, uncertainties, and issues arising during QA/QC. Revise key category analysis based on the newly completed inventory to aid in decisions regarding future priorities.

## 1.4 ORGANISATION OF VOLUME 4 IN 2006 IPCC GUIDELINES

The material in Volume 4 should be used as follows:

- Chapter 2 describes generic methods for carbon pools and biomass burning that can be applied within each of the six land-use categories, i.e., the methods are not specific to a particular land use. These consist of estimating ecosystem C stock changes and CO<sub>2</sub> and non-CO<sub>2</sub> emissions from fires and biomass burning. To avoid redundancy in the subsequent land-use specific chapters, Chapter 2 provides guidance on choice of method and decision trees for tier selection. Tier 1 equations are provided along with tables of generic emission factors and other parameters.
- Chapter 3 deals with the consistent representation of land. In particular, the multiple approaches for classification of land-use categories are presented in this chapter, along with the level of disaggregation. Users will find this material helpful for understanding the general issues surrounding representation of systems, which will be needed later in order to use the estimation methods that are specific to a particular



land-use and/or source category. After consulting Chapter 2 and Chapter 3, users should proceed to the appropriate chapter addressing the issues specific to a particular land-use or source category.

- Chapters 4 to 9 provide information for specific land-use categories. These chapters contain information on the application of the generic methods described in Chapter 2 and they also contain full method descriptions and application for any land-use specific methods.
  - Chapter 4 deals with estimation of emissions and removals from forest lands. Separate sections cover *Forest Land Remaining Forest Land* and *Land Converted to Forest Land*. Harvested wood products are addressed separately in Chapter 12.
  - Chapter 5 deals with estimation of emissions and removals from cropland. Separate sections cover *Cropland Remaining Cropland* and *Land Converted to Cropland*. Methane production from rice cultivation, which is specific to cropland, is also addressed in this chapter.
  - Chapter 6 deals with estimation of emissions and removals from the Grassland. Separate sections cover *Grassland Remaining Grassland* and *Land Converted to Grassland*.
  - Chapter 7 deals with estimation of emissions and removals from Wetlands, including peat extraction in natural peatlands and flooded lands. Methods specific to wetlands, for estimation of CO<sub>2</sub> and CH<sub>4</sub> emissions, are provided in Appendices with a basis for future methodological development.
  - Chapter 8 deals with estimation of emissions and removals from Settlements. Separate sections cover *Settlements Remaining Settlements* and *Land Converted to Settlements*.
  - Chapter 9 deals with ‘Other Land’, which includes areas with bare soil, rock, and ice, in addition to all land areas that do not fall into the other five land-use categories treated in Chapters 4 to 8. Since greenhouse gas emissions and removals are not reported for unmanaged lands, methods and guidance in this chapter apply only to ‘*Land Converted to Other Land*’, for example, from extreme degradation of forest, cropland or grassland to barren land that is no longer managed for useful purposes.
- Chapter 10 provides guidance on livestock related emissions, including methane emissions from enteric fermentation and CH<sub>4</sub> and N<sub>2</sub>O (direct and indirect) emissions from manure management.
- Chapter 11 provides guidance for emissions sources from managed soils, associated primarily with application of fertilizer, crop residues, manure, lime, and urea to soils. Specifically, methods and guidance are provided for estimating N<sub>2</sub>O emissions from managed soils and CO<sub>2</sub> emissions from liming and urea applications. Activity data for these sources are typically not broken out by individual land use, hence Tier 1 methods are based on (national) aggregate data.
- Chapter 12 provides methodological guidance for estimation of C stock changes and emissions from harvested wood products, and is neutral with regards to the multiple alternative approaches to inventory estimation that are given.

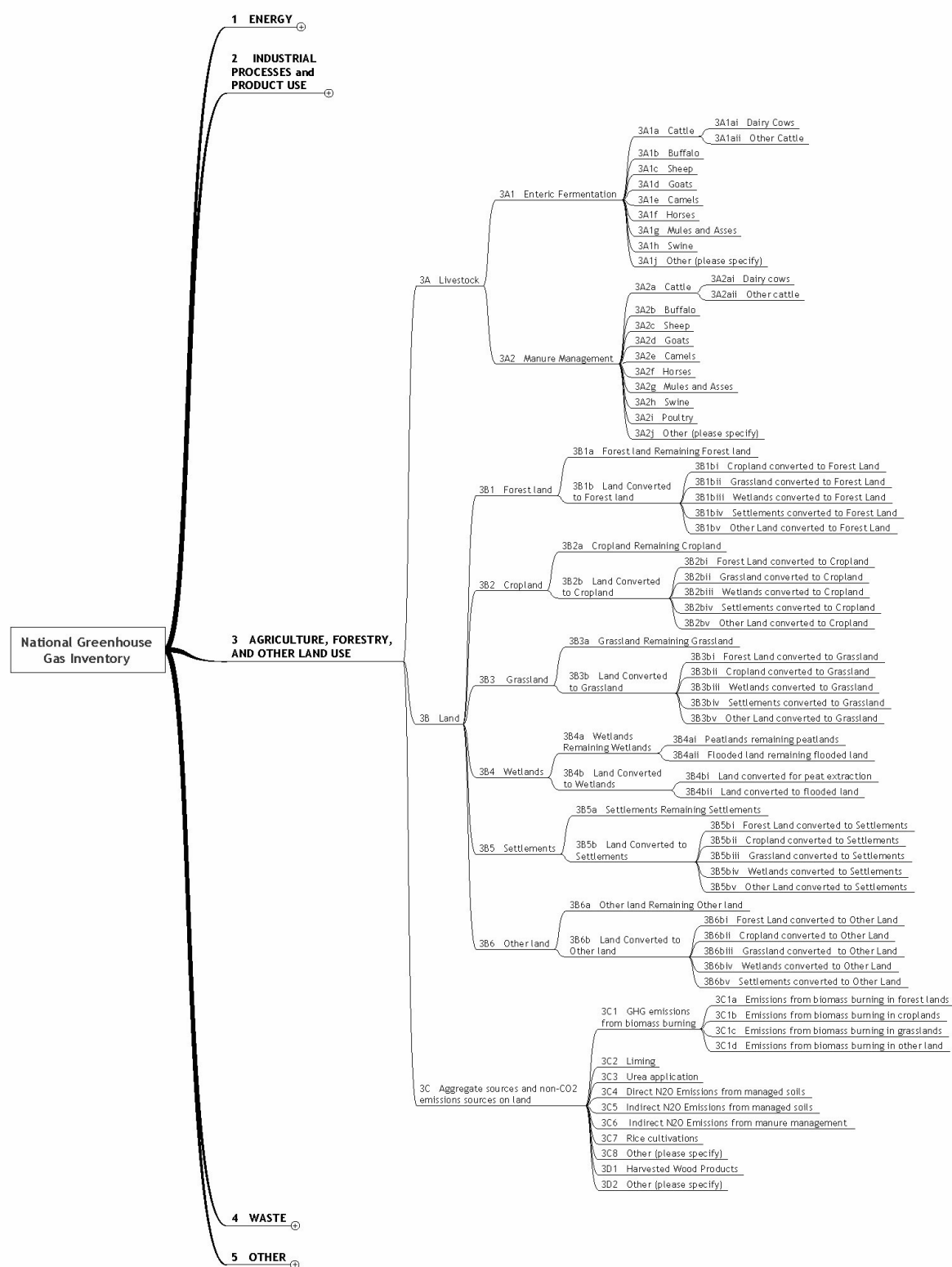
Figure 1.4 presents the structure of AFOLU reporting with categories (including category codes) that are listed in Table 8.2 of Volume 1.

Annex 1 provides worksheets for each sub-category that can be used to estimate emissions based on Tier 1 methods and appropriate emission/stock change factors and activity data. The Reporting Tables for the greenhouse gas emissions/removals at sectoral and national levels are provided in Volume 1 Chapter 8 of the Guidelines.

Annex 2 is the summary of all equations in AFOLU that serves as quick reference for inventory compilers.

Table 1.2 provides the summary information as to what carbon pools and activities emitting non-CO<sub>2</sub> gases in each land-use category are treated under Tier 1 methods; in what section in AFOLU Volume the guidance are discussed, and their reference to the *1996 IPCC Guidelines*.



**Figure 1.4 Structure of AFOLU Reporting**

| <b>TABLE 1.2</b><br><b>LAND-USE CATEGORIES, CARBON POOLS AND NON-CO<sub>2</sub> GASES TO BE ESTIMATED UNDER TIER 1, THEIR RELEVANCE TO AFOLU SECTIONS, AND THE REFERENCE TO 1996 IPCC GUIDELINES</b> |  |   |                        |                         |  |                      |
|--|--|---|------------------------|-------------------------|--|----------------------|
| <b>Land-use category/<br/>Chapter</b>  | <b>Subcategory</b>                     | <b>C pool &amp; non-CO<sub>2</sub> gases</b>            | <b>Methods Section</b> | <b>Chapter 2 Method</b> | <b>Linkage to 1996 IPCC Guidelines</b> | <b>Tier 1 Method</b> |
| <b>Forest Land<br/>(Chapter 4)</b>   | Forest Land Remaining Forest Land (FF) | Above-ground biomass                                    | 4.2.1                  | 2.3.1.1                 | 5A                                     | ⊕                    |
|  |  | Below-ground biomass                                    | 4.2.1                  | 2.3.1.1                 | NE                                     | ⊕                    |
|  |  | Dead organic matter                                     | 4.2.2                  | 2.3.2.1                 | NE                                     | 0                    |
|  |  | Soil carbon   | 4.2.3                  | 2.3.3.1                 | 5D                                     | ⊕ <sup>1</sup>       |
|  |  | Non-CO <sub>2</sub> from biomass burning                | 4.2.4                  | 2.4.1                   | NE                                     | ⊕                    |
|  | Land Converted to Forest Land (LF)     | Above-ground biomass                                    | 4.3.1                  | 2.3.1.2                 | 5A, 5C                                 | ⊕                    |
|  |  | Below-ground biomass                                    | 4.3.1                  | 2.3.1.2                 | NE                                     | ⊕                    |
|  |  | Dead organic matter                                     | 4.3.2                  | 2.3.2.2                 | NE                                     | ⊕                    |
|  |  | Soil carbon   | 4.3.3                  | 2.3.3.1                 | 5D                                     | ⊕                    |
|  |  | Non-CO <sub>2</sub> from biomass burning                | 4.3.4                  | 2.4.1                   | 4E, 4F                                 | ⊕                    |
| <b>Cropland<br/>(Chapter 5)</b>  | Cropland Remaining Cropland (CC)       | Above-ground biomass                                    | 5.2.1                  | 2.3.1.1                 | 5A                                     | ⊕                    |
|  |  | Dead organic matter                                     | 5.2.2                  | 2.3.2.1                 | NE                                     | 0                    |
|  |  | Soil carbon   | 5.2.3                  | 2.3.3.1                 | 5D                                     | ⊕                    |
|  |  | Non-CO <sub>2</sub> from crop residue burning           | 5.2.4                  | 2.4.1                   | 4F                                     | ⊕                    |
|  |  | Methane emissions from rice                             | 5.5                    | -                       | 4C                                     | ⊕                    |
|  | Land Converted to Cropland (LC)        | Above-ground biomass                                    | 5.3.1                  | 2.3.1.2                 | 5B                                     | ⊕                    |
|  |  | Dead organic matter                                     | 5.3.2                  | 2.3.2.2                 | NE                                     | ⊕                    |
|  |  | Soil carbon   | 5.3.3                  | 2.3.3.1                 | 5D                                     | ⊕                    |
|  |  | Non-CO <sub>2</sub> from biomass (crop residue) burning | 5.3.4                  | 2.4                     | 4E, 5B                                 | ⊕                    |

| <b>TABLE 1.2 (CONTINUED)</b><br><b>LAND-USE CATEGORIES, CARBON POOLS AND NON-CO<sub>2</sub> GASES TO BE ESTIMATED UNDER TIER 1, THEIR RELEVANCE TO AFOLU SECTIONS, AND THE REFERENCE TO 1996 IPCC GUIDELINES</b> |  |  |                        |                         |  |                      |
|--|--|--|------------------------|-------------------------|--|----------------------|
| <b>Land-use category/<br/>Chapter</b>  | <b>Subcategory</b>                       | <b>C pool &amp; non-CO<sub>2</sub> gases</b> | <b>Methods Section</b> | <b>Chapter 2 Method</b> | <b>Linkage to 1996 IPCC Guidelines</b> | <b>Tier 1 Method</b> |
| <b>Grassland<br/>(Chapter 6)</b>   | Grassland Remaining Grassland (GG)       | Above-ground biomass                         | 6.2.1                  | 2.3.1.1                 | 5A                                     | 0                    |
|  |  | Dead organic matter                          | 6.2.2                  | 2.3.2.1                 | NE                                     | 0                    |
|  |  | Soil carbon                                  | 6.2.3                  | 2.3.3.1                 | 5D                                     | ⊕                    |
|  |  | Non-CO <sub>2</sub> from biomass burning     | 6.2.4                  | 2.4                     | 4E                                     | ⊕                    |
|  | Land Converted to Grassland (LG)         | Above-ground biomass                         | 6.3.1                  | 2.3.1.2                 | 5B                                     | ⊕                    |
|  |  | Dead organic matter                          | 6.3.2                  | 2.3.2.2                 | NE                                     | ⊕                    |
|  |  | Soil carbon                                  | 6.3.3                  | 2.3.3.1                 | 5D                                     | ⊕                    |
|  |  | Non-CO <sub>2</sub> from biomass burning     | 6.3.4                  | 2.4                     | 4F, 5B                                 | ⊕                    |
| <b>Wetlands<br/>(Chapter 7)</b>  | Peatlands Remaining Peatlands            | CO <sub>2</sub> emissions                    | 7.2.1.1                | -                       | NE                                     | ⊕                    |
|  |  | Non-CO <sub>2</sub> emissions                | 7.2.1.2                | -                       | NE                                     | ⊕                    |
|  | Land Being Converted for Peat Extraction | CO <sub>2</sub> emissions                    | 7.2.2.1                | -                       | NE                                     | NA                   |
|  |  | Non-CO <sub>2</sub> emissions                | 7.2.2.2                | -                       | NE                                     | ⊕                    |
|  | Flooded Land Remaining Flooded Land      | CO <sub>2</sub> emissions                    | NG                     | -                       | NE                                     | ⊕                    |
|  |  | Non-CO <sub>2</sub> emissions                | Appendix 3             | -                       |  | ⊕                    |
|  | Land Converted to Flooded Land           | CO <sub>2</sub> emissions                    | 7.3.2 Appendix 2       | -                       | NE                                     | ⊕                    |
|  |  | Non-CO <sub>2</sub> emissions                | Appendix 3             | -                       |  | ⊕                    |
| <b>Settlements<br/>(Chapter 8)</b>   | Settlements Remaining Settlements (SS)   | Above-ground biomass                         | 8.2.1                  | 2.3.1.1                 | 5A                                     | 0                    |
|  |  | Dead organic matter                          | 8.2.2                  | 2.3.2.1                 | NE                                     | 0                    |
|  |  | Soil carbon                                  | 8.2.3                  | 2.3.3.1                 | NE                                     | ⊕ <sup>1</sup>       |
|  | Land Converted to Settlements (LS)       | Above-ground biomass                         | 8.3.1                  | 2.3.1.2                 | 5B                                     | ⊕                    |
|  |  | Dead Organic Matter                          | 8.3.2                  | 2.3.2.2                 | NE                                     | ⊕                    |
|  |  | Soil carbon                                  | 8.3.3                  | 2.3.3.1                 | NE                                     | ⊕                    |
| <b>Other Land<br/>(Chapter 9)</b>  | Land Converted to Other Land (LO)        | Above-ground biomass                         | 9.3.1                  | 2.3.1.2                 | 5B                                     | ⊕                    |
|  |  | Dead Organic Matter                          | 9.3.2                  | 2.3.2.2                 | NE                                     | NA                   |
|  |  | Soil carbon                                  | 9.3.3                  | 2.3.3.1                 | NE                                     | ⊕                    |

| <b>TABLE 1.2 (CONTINUED)</b><br><b>LAND-USE CATEGORIES, CARBON POOLS AND NON-CO<sub>2</sub> GASES TO BE ESTIMATED UNDER TIER 1, THEIR RELEVANCE TO AFOLU SECTIONS, AND THE REFERENCE TO 1996 IPCC GUIDELINES</b>   |                      |  |                        |                         |  |                      |
|--|----------------------|--|------------------------|-------------------------|--|----------------------|
| <b>Land-use category/ Chapter</b>  | <b>Subcategory</b>   | <b>C pool &amp; non-CO<sub>2</sub> gases</b> | <b>Methods Section</b> | <b>Chapter 2 Method</b> | <b>Linkage to 1996 IPCC Guidelines</b> | <b>Tier 1 Method</b> |
| <b>Livestock (Chapter 10)</b>  | Enteric Fermentation | CH <sub>4</sub> emissions                    | 10.3                   | -                       | 4A                                     | ⊕                    |
|  | Manure Management    | CH <sub>4</sub> emissions                    | 10.4                   | -                       | 4B                                     | ⊕                    |
|  |                      | N <sub>2</sub> O emissions                   | 10.5                   | -                       | 4B                                     | ⊕                    |
| <b>Managed soils (Chapter 11)</b>  | Soil Management      | N <sub>2</sub> O emissions                   | 11.2                   | -                       | 4D                                     | ⊕                    |
|  | Liming               | CO <sub>2</sub> emissions                    | 11.3                   | -                       | —                                      | ⊕                    |
|  | Urea Fertilization   | CO <sub>2</sub> emissions                    | 11.4                   | -                       | NE                                     | ⊕                    |
| <b>Harvested wood products (Chapter 12)</b>  | Wood Products        | C stock changes                              | Chapter 12             | -                       | NE                                     | ⊕ <sup>2</sup>       |
| <p>The 1996 IPCC Guidelines cover the following categories: 5A Changes in Forest and Other Woody Biomass Stocks; 5B Forest and Grassland Conversion; 5C Abandonment of Managed Lands; 5D Emissions and Removals from Soils, and 5E Other (Reporting Instructions p. 1.14 - 1.16)</p> <p>NE: not estimated under default method in the 1996 IPCC Guidelines<br/> NG – no guidance provided in the Guidelines</p> <p>Notes for column “Tier 1 Method”:<br/> ⊕ - Tier 1 methods and default parameters are available in the Guidelines.<br/> 0 = Tier 1 (default) assumption is that emissions are zero or in equilibrium; no methods and parameters are provided in the Guidelines.<br/> 1 = Tier 1 and default parameters available only for organic soils.<br/> 2 = Tier 1 method available to estimate HWP variables which may be used to compute HWP Contribution to AFOLU.<br/> NA – not applicable</p> |                      |  |                        |                         |  |                      |

## Annex 1A      **Historical background on IPCC greenhouse gas inventory guidance for AFOLU Sector**

### 1A.1      **Revised 1996 IPCC Guidelines**

The emission and removal categories covered together in Volume 4 of the *2006 IPCC Guidelines* were previously separated in different chapters of the *1996 IPCC Guidelines* (IPCC, 1997): Chapter 4 (Agriculture) and Chapter 5 (Land-Use Change and Forestry, LUCF). The fundamental basis for the methodology in LUCF rested upon two linked themes: i) that the flux of CO<sub>2</sub> to and from the atmosphere can be equated to changes in terrestrial carbon stocks and product pools, and ii) changes in carbon stocks can be estimated by determining land use and management (e.g., logging, burning, tillage, grazing, etc.) at various points in time. Simple assumptions are then applied about their impact on carbon stocks and biological response to a given land-use and management system. In contrast, the Agricultural chapter dealt only with direct flux estimates from different source categories and therefore did not incorporate the stock change concept.

### **AGRICULTURE (CHAPTER 4 IN THE REVISED 1996 IPCC GUIDELINES)**

The *1996 IPCC Guidelines* focused on activities associated with managed agricultural systems and that are potentially large sources of emissions in a country, including:

- **CH<sub>4</sub> emissions from enteric fermentation in domestic livestock.** Methane is produced as a by-product of enteric fermentation, where ruminant animals (e.g., cattle, sheep) are the major source but some non-ruminant animals (e.g., pigs, horses) also emit CH<sub>4</sub>.
- **CH<sub>4</sub> and N<sub>2</sub>O emissions from manure management.** Methane is produced from the decomposition of manure under anaerobic conditions while N<sub>2</sub>O is produced under aerobic or mixed aerobic/anaerobic conditions. Hence emissions of each gas depend on the type of manure and the storage system.
- **CH<sub>4</sub> emissions from rice cultivation.** Anaerobic decomposition of organic material in flooded rice fields produces methane, which escapes to the atmosphere primarily through air-bubbles and by transport through the rice plants. The amount emitted is a function of rice species, number and duration of harvests, soil type and temperature, irrigation method, and fertilizer use.
- **CH<sub>4</sub>, N<sub>2</sub>O, CO, NO<sub>x</sub> emissions from prescribed burning of savannas (or other types of grassland) and crop residues.** Burning of savannas and crop residues does not create a net-release of CO<sub>2</sub> to the atmosphere because vegetation regrows between burning cycles. However, burning releases other gases that are either direct or indirect sources of greenhouse gases, including CH<sub>4</sub>, N<sub>2</sub>O, CO, and NO<sub>x</sub>.
- **Emissions of N<sub>2</sub>O from soils.** Produced through microbial processes in soils, emissions are largely a function of the amount of nitrogen added to soils from (1) synthetic fertilizers, (2) animal waste, (3) biological fixation, (4) crop residues, and (5) sewage sludge or other organic N additions, which can be emitted ‘directly’ where the N is applied, or ‘indirectly’, from N leached as NO<sub>3</sub> or volatilized as NH<sub>3</sub> and NO<sub>x</sub> and redeposited in other locations.

### **LUCF (CHAPTER 5 IN THE REVISED 1996 IPCC GUIDELINES)**

The inventory methods for Land-Use Change and Forestry (LUCF) focused on the most important land-use and management changes that result in CO<sub>2</sub> emissions and removals, including four broad categories:

- **Changes in forest and other woody biomass stocks.** Effects of human interaction with forests and wood products are considered in a single broad category, which includes commercial management, harvest of industrial roundwood (logs) and fuelwood, production and use of wood commodities, and establishment and operation of forest plantations as well as planting of trees in urban, village and other non-forest locations.
- **Forest and grassland conversion.** Conversion of forests and grasslands to pasture, cropland or other managed land uses, can significantly reduce carbon stores in biomass and soils. Deforestation is an example of this type of conversion.

- **Abandonment of managed lands (croplands, pastures, plantation forests, or other managed lands).** Abandoned lands often accrue carbon in biomass and soils over time, particularly if the conditions approach those found in natural grasslands or forests.
- **CO<sub>2</sub> Emissions and removals from soils.** Changing management can alter the CO<sub>2</sub> emissions and removals from soils, particularly through adoption of conservation practices or increasing crop and forage production.

The 1996 *IPCC Guidelines* briefly described general issues and methodological approaches for other possible categories such as below-ground biomass, natural disturbances (including fire), shifting cultivation and flooding and drainage of wetlands. The methods also addressed release of non-CO<sub>2</sub> trace gases (CH<sub>4</sub>, CO, N<sub>2</sub>O, NO<sub>x</sub>) from the open burning of biomass from forest clearing.

## 1A.2 Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (*GPG2000*)

*GPG2000* (IPCC, 2000) provided supplementary information to the 1996 *IPCC Guidelines* to improve inventory transparency, documentation, consistency over time, completeness, and comparability. *GPG2000* also provided methods for addressing uncertainties and implementing quality control and quality assurance. In the Agriculture Sector, guidance was provided for all of the emission sources included in the 1996 *IPCC Guidelines* (see above).

*GPG2000* introduced a method for identifying key sources that should be given high priority because of their significance in affecting the absolute level or trend in emissions, their uncertainty, or qualitative factors such as unexpectedly high or low estimates. The goal of this method is to provide practical guidance on how to develop a national inventory with an efficient use of resources, identifying sources that are candidates for using a more detailed (higher tier) estimation method.

## 1A.3 Good Practice Guidance for Land Use, Land-Use Change and Forestry (*GPG-LULUCF*)

*GPG-LULUCF* (IPCC, 2003) elaborated on the 1996 *IPCC Guidelines* to adopt an approach based on land-use categories for organizing the methodologies and *good practices* associated with estimating emissions and removals in the Land Use, Land-Use Change and Forestry (LULUCF) Sector, including Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. Each land category was further sub-divided into land remaining in the same category (e.g., *Forest Land Remaining Forest Land*) or land converted to another land category (e.g., Grassland converted to Forest Land). Methods for estimating carbon stock changes associated with harvested wood products (HWP) were included as an appendix, reflecting the unresolved issues and ongoing negotiations of including HWP in national inventories. As with *GPG2000*, *GPG-LULUCF* adopted the hierarchical Tier approach for methods descriptions, as well as the concept of key source categories, and similarly included guidance on quality assurance/quality control (QA/QC), reconstruction of missing data, time series consistency, sampling techniques, quantification and combination of uncertainties, and verification.

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