CHAPTER 1

INTRODUCTION

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1 INTRODUCTION

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 and that often the same practices influence both Agriculture and Land Use, Land Use Change and Forestry. This approach is intended to improve consistency and completeness in the estimation and reporting of greenhouse gas emissions and removals. The refinement builds on this objective by providing updates to the guidance in terms of improved emission factors, new methodologies, and examples for compilers to better understand the estimation of emissions and removals in the AFOLU sector.

The principal changes made in the *2006 IPCC Guidelines* and *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2019 Refinment)*, as compared with the *Revised 1996 IPCC Guidelines* (for both Agriculture, and Land-Use Change and Forestry, continue to reflect the elaborations of the *Revised 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_2 emissions from managed soils and biomass burning, and livestock population characterization and manure management systems from Agriculture (Chapter 5 of the *Revised 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_2 and non-CO_2 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_2 and CH_4 emissions from flooded land.

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[1]. While recognizing this complexity, inventory methods need to be practical and operational.

The *2006 IPCC Guidelines* and this *2019 Refinement* 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. The IPCC describes the Managed Land Proxy (MLP) as an approach to approximate estimates of anthropogenic emissions and removals, but this proxy estimate also contains emissions and removals resulting from natural disturbances.

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 *2019 Refinement*. 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_2 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.

However, some of the emissions and removals from managed land are characterised by high interannual variability. Interannual variability (IAV) refers to the variability in the annual emissions and removals estimates between years within a time series. In the AFOLU sector, the application of the MLP means that IAV can be caused by both anthropogenic and natural causes. The three main causes of IAV in GHG emissions and removals in the AFOLU sector are (1) natural disturbances (such as wildfires, insects, windthrow, and ice storms), which can cause large immediate and delayed emissions and kill trees; (2) climate variability (e.g. temperature, precipitation, and drought), which affects photosynthesis and respiration; and (3) variation in the rate of human activities, including land use (such as forest harvesting), and land-use change.

When the MLP is used and the interannual variability in emissions and removals due to natural disturbance is large, it is difficult to gain a quantitative understanding of the role of human activities compared to the impacts of natural effects. In such situations disaggregating[2] MLP emissions and removals into human and natural effects may provide increased understanding and refined estimates of the emissions and removals that are due to human activities such, land use (including harvesting) and land-use change. In this way, disaggregation can contribute to improved quantification of the trends in emissions and removals due to human activities and mitigation actions that are taken to reduce anthropogenic emissions and preserve and enhance carbon stocks.

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

- CO_2 emissions and removals resulting from C stock changes in biomass, dead organic matter and mineral soils, for all managed lands;
- CO_2 and non-CO_2 emissions from fire on all managed land;
- Optional guidance that may be used by countries that choose to disaggregate their reported MLP emissions and removals (i.e. all emissions and removals on managed land) into those that are considered to result from human activities and those that are considered to result from natural disturbances;
- N_2O emissions from all managed soils;
- CO_2 emissions associated with liming and urea application to managed soils;
- CH_4 emissions from rice cultivation;

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

[2] Disaggregating means that an estimate is separated into its component parts.

- CO_2 and N_2O emissions from cultivated organic soils;
- CO_2 and N_2O emissions from managed wetlands, and CH_4 emissions from flooded land;
- CH_4 emission from livestock (enteric fermentation);
- CH_4 and N_2O 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

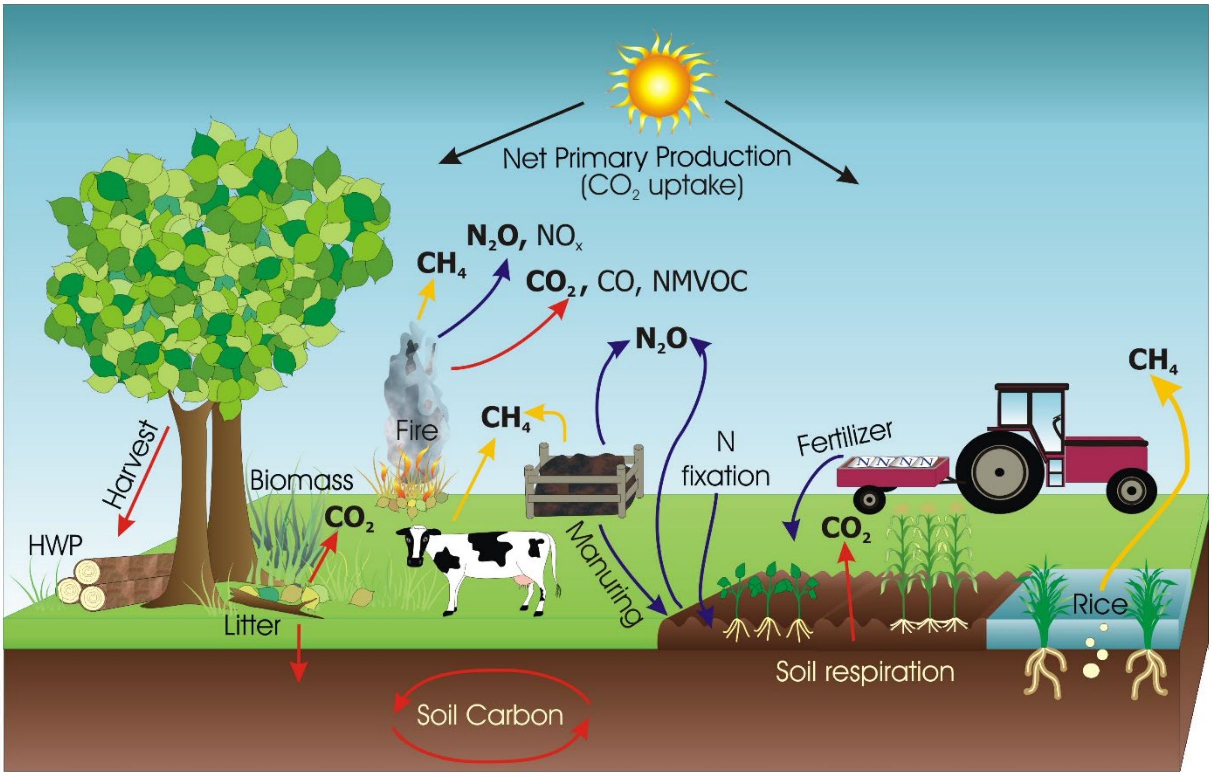
1.2.1 Science background

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).

Greenhouse Gases in AFOLU

The key greenhouse gases of concern are CO_2, N_2O and CH_4. 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. N_2O is primarily emitted from ecosystems as a by-product of nitrification and denitrification, while CH_4 is emitted through methanogenesis under anaerobic conditions in soils and manure storage, through enteric fermentation, and during incomplete combustion while burning organic

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



matter. Other gases of interest (from combustion and from soils) are NO_x, NH_3, NMVOC and 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 NO_3^- losses from soils, some of which can be subsequently converted to N_2O through denitrification.

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 CO_2 fluxes) and 2) directly as gas flux rates to and from the atmosphere (used for estimating non-CO_2 emissions and some CO_2 emissions and removals). The use of C stock changes to estimate CO_2 emissions and removals, is based on the fact that changes in ecosystem C stocks are predominately (but not exclusively) through 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 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 CO_2. Non-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 CO_2 removal from the atmosphere. Large amounts of CO_2 are transferred between the atmosphere and terrestrial ecosystems, primarily through photosynthesis and respiration. The uptake of 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).

Net Ecosystem Production (NEP) = Net Primary Production (NPP) – 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 [3].

Net Biome Production (NBP) = NEP – 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 Land. 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 Land, leading to significant losses of biomass carbon. Fires not only return CO_2 to the atmosphere through combustion of biomass, but also emit other greenhouse gases, directly or indirectly, including CH_4, N_2O, NMVOC, NO_x 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_2, N_2O, CH_4, NO_x, NMVOC, and CO.

[3] 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.

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 or bound in 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. Biochar C[4] may be produced through pyrolysis and amended to soils with a long turnover time.

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_4. This can be a major source of emissions in countries with a considerable amount of land dedicated to paddy rice production or are flooded land (e.g., reservoirs created by constructing dams on rivers). 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_4 are consumed (oxidized) by methanotrophic bacteria although this impact on CH_4 removals is not addressed in the current guidance due to limited studies for quantifying the impact.[5]

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_2 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_2.

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_2O emissions from soils as a by-product of nitrification and denitrification. Nitrogen additions (in dung and urine) by grazing animals can also stimulate N_2O emissions. Similarly, land-use change enhances N_2O emissions if associated with heightened decomposition of soil organic matter and subsequent N mineralization, such as initiating cultivation on wetlands, forests or grasslands.

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_4. Management decisions about manure disposal and storage affect emissions of CH_4 and N_2O,

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[4] Biochar is a solid carbonised product from thermochemical conversion through pyrolysis (heating with limited air). The term biochar is used herein only to refer to materials that have been produced under process conditions in which relatively easily mineralisable organic materials are converted to more persistent forms by heating to above 350°C with limited air through a gasification or pyrolysis process. No default methodology is provided for biochar C amendments, but guidance is provided for Tier 2 and 3 methods. However, this guidance does not deal with pyrolytic organic materials that result from wild fires or open fires, and is only applicable for biochar added to mineral soils.

[5] No default methodology exists for estimation of CH_4 removals in aerobic soils because of limited studies addressing land-use and management impacts on methane oxidation. However, there is evidence that disturbance through land-use change and addition of nitrogen (i.e., as fertilizer) may reduce rates of methane oxidation. Countries that wish to estimate and report CH_4 removals should develop, validate and document an appropriate national methodology for estimating CH_4 removals, including analysis of uncertainty. It is good practice for countries reporting CH_4 removals to also ensure symmetry by including all emissions of CH_4 on lands were CH_4 removals are reported.

which occur result from methanogenesis in decomposing manures and as a by-product nitrification/ denitrification. Furthermore, volatilization losses of NH_3 and NO_x and losses of N in leaching and runoff from manure management systems and soils leads to indirect greenhouse gas emissions.

1.2.2 Carbon pool definitions and non-CO_2 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_2 gases of primary concern for the AFOLU Sector are methane (CH_4) and nitrous oxide (N_2O). Emissions of other nitrogenous gases including NO_x and NH_3, which can serve as a source of subsequent N_2O emissions (and hence referred to as *indirect* emission sources), are also considered (see Chapters 10 and 11).

TABLE 1.1 (UPDATED)
DEFINITIONS FOR CARBON POOLS USED IN AFOLU FOR EACH LAND-USE CATEGORY

Pool		Description
Biomass	Above-ground biomass	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage. 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.
Dead organic matter	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.
Soils	Soil organic matter[1]	Includes organic carbon in mineral soils to a specified depth chosen by the country and applied consistently through the time series[2,3]. 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.

[1] 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_2 emissions from liming and urea applications to soils are estimated as fluxes using Tier 1 or Tier 2 methods.

[2] Carbon stocks in organic soils are not explicitly computed using Tier 1 or Tier 2 methods, (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.

[3] Biochar C amendments are estimated separately and includes all C added to soils without regard to depth for Tier 2 methods. No default method is provided.

1.3 OVERVIEW OF INVENTORY PREPARATION FOR THE AFOLU SECTOR

To prepare inventories for the AFOLU Sector, emissions and removals of CO_2 and non-CO_2 greenhouse gases are estimated separately for each of six land-use categories. Other CO_2 emission and non-CO_2 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.

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_2 (as carbon stock changes) from biomass, dead organic matter and soils, as well as non-CO_2 emissions from burning and, depending on the land-use category, emissions from other specific sources (e.g. CH_4 emissions from rice and flooded land).

CH_4 and N_2O 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_2 emissions from liming and from urea application to managed soils are typically estimated using aggregate data (e.g., national-level).

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 reduces uncertainty in the inventory, 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. There are few exceptions with alternative methodologies to derive country-specific factors for Tier 2 (e.g., gross energy intake calculations to estimate methane emissions from enteric fermentation). Tier 3 methods are not described in detail, but *good practice* in application is outlined and some examples are provided in information boxes.

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. For a few source categories, methodologies are provided for estimating a country-specific emission and stock change factors (e.g., CH_4 emissions from enteric fermentation).

At **Tier 3**, higher order methods are used, such as process-based 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.

1.3.3 Identification of *key categories*

No refinement.

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), which is based on combinations of management practices (e.g., tillage and fertiliser management in Croplands). 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, crop yields, biochar C (Tier 2 and 3 only), 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; biochar C amendment data are stratified by Cropland and Grassland as in Step 2).
5. Estimate CO_2 emissions and removals and non-CO_2 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_2 emissions and removals and non-CO_2 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_2 emissions and removals and non-CO_2 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 analysed separately for each land-use category).
9. Transcribe summary information into reporting tables, converting C stock changes to emissions or removals of CO_2 and entering non-CO_2 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 2019 REFINEMENT TO THE 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_2 and non-CO_2 emissions from fires and biomass burning. To avoid redundancy in the subsequent land-use specific chapters, Tier 1 equations are provided along with tables of generic emission factors and other parameters. Chapter 2 also provides guidance on choice of method and decision trees for tier selection including general guidance for Tier 2 emission factors on how to use allometric models and biomass maps; and guidance on how to parameterize and evaluate Tier 3 models, the integration of data to models, estimating uncertainties and means to increase its transparency. Some case studies demonstrating how parties have developed and worked with Tier 3 methods are presented in information boxes. In addition, Chapter 2 provides an optional approach that may be used by countries that choose to disaggregate their reported MLP emissions and removals (i.e. all emissions and removals (E/R) on managed land) into those that are considered to result from human activities and those that are considered to result from natural disturbances (ND). In particular, the approach describes a generic method to reduce interannual variability of E/R due to natural disturbances and increase the proportion of the anthropogenic contribution reported in the MLP by disaggregating from the total flux the component which is attributed to ND. The remaining E/R quantifies the anthropogenic component of E/R on managed land as the total minus that from ND. This estimate may still be somewhat affected by ND and other natural effects, but less so compared to the total E/R estimated using the MLP. Because the goal of the national GHG Inventories is to estimate and report anthropogenic E/R, the approach is proposed as a refined estimate of the anthropogenic E/R. The reason that the approach has limited the disaggregation to E/R from ND is because scientific methods to quantify all-natural effects are currently not available. Where a country choses to disaggregate E/R from ND from the remaining anthropogenic E/R estimated using the MLP, it is *good practice* to report the total MLP E/R and the two disaggregated components, and to document the methods and assumptions used.
- 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*. CH_4 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, including estimation of CO_2 and CH_4 emissions.
- 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 CH_4 emissions from enteric fermentation and CH_4 and N_2O (direct and indirect) emissions from manure management. The guidance provides different options to adapt emission estimates to consider the productivity of the livestock systems and assures consistency among emission estimates for different sources of emissions resulting from livestock production.
- 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_2O emissions from managed soils and CO_2 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_2 gases in each land-use category are treated under Tier 1 methods; in what section in AFOLU Volume the guidance is discussed, and their reference to the *Revised 1996 IPCC Guidelines*.

Figure 1.4 Structure of AFOLU Reporting

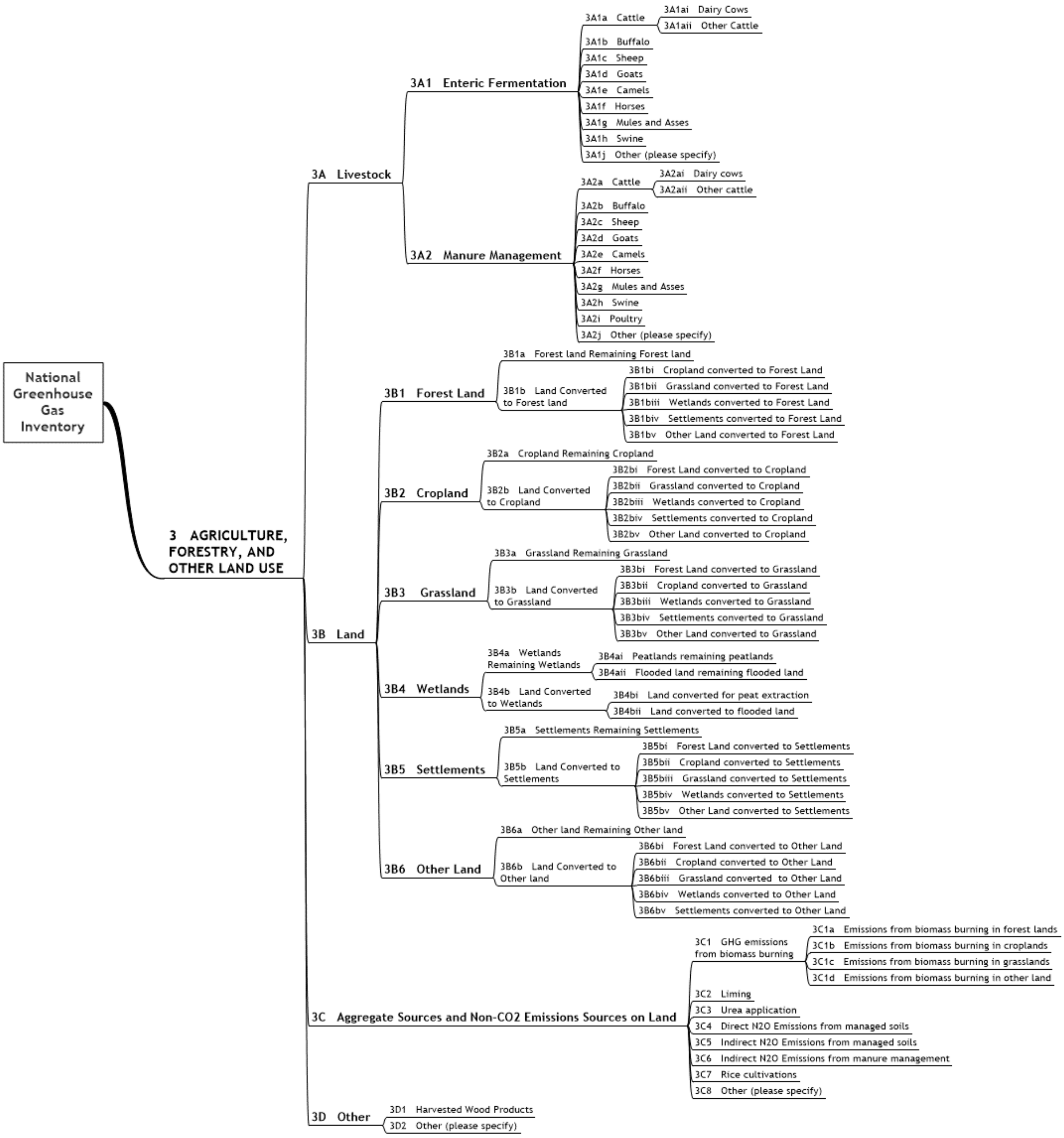

TABLE 1.2 (UPDATED)
LAND-USE CATEGORIES, CARBON POOLS AND NON-CO_2 GASES TO BE ESTIMATED UNDER TIER 1, THEIR RELEVANCE TO AFOLU SECTIONS, AND THE REFERENCE TO *REVISED 1996 IPCC GUIDELINES*

Land-use category/ Chapter	Subcategory	C pool & non-CO_2 gases	Methods Section	Chapter 2 Method	Linkage to *Revised 1996 IPCC Guidelines*	Tier 1 Method
Forest Land (Chapter 4)	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	⊕ [1]
		Non-CO_2 from biomass burning	4.2.4	2.4	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_2 from biomass burning	4.3.4	2.4	4E, 4F	⊕
Cropland (Chapter 5)	Cropland Remaining Cropland (CC)	Above-ground biomass	5.2.1	2.3.1.1	5A	⊕[3]
		Dead organic matter	5.2.2	2.3.2.1	NE	0
		Soil carbon	5.2.3	2.3.3.1	5D	⊕
		Non-CO_2 from crop residue burning	5.2.4	2.4	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_2 from biomass (crop residue) burning	5.3.4	2.4	4E, 5B	⊕

TABLE 1.2 (UPDATED) (CONTINUED)
LAND-USE CATEGORIES, CARBON POOLS AND NON-CO_2 GASES TO BE ESTIMATED UNDER TIER 1, THEIR RELEVANCE TO AFOLU SECTIONS, AND THE REFERENCE TO *REVISED 1996 IPCC GUIDELINES*

Land-use category/ Chapter	Subcategory	C pool & non-CO_2 gases	Methods Section	Chapter 2 Method	Linkage to *Revised 1996 IPCC Guidelines*	Tier 1 Method
Grassland (Chapter 6)	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_2 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_2 from biomass burning	6.3.4	2.4	4F, 5B	⊕
Wetlands (Chapter 7)	Peatlands Remaining Peatlands	CO_2 emissions	7.2.1.1	-	NE	⊕
		Non-CO_2 emissions	7.2.1.2	-	NE	⊕
	Land Being Converted for Peat Extraction	CO_2 emissions	7.2.2.1	-	NE	NA
		Non-CO_2 emissions	7.2.2.2	-	NE	⊕
	Flooded Land Remaining Flooded Land	CO_2 emissions	7.3.1.1	-	NE	0
		Non-CO_2 emissions	7.3.1.2	-	NE	⊕
	Land Converted to Flooded Land	CO_2 emissions	7.3.2.1	-	NE	⊕
		Non-CO_2 emissions	7.3.2.2	-	NE	⊕
Settlements (Chapter 8)	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	⊕[1]
	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	⊕
Other Land (Chapter 9)	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	⊕

TABLE 1.2 (UPDATED) (CONTINUED)
LAND-USE CATEGORIES, CARBON POOLS AND NON-CO_2 GASES TO BE ESTIMATED UNDER TIER 1, THEIR RELEVANCE TO AFOLU SECTIONS, AND THE REFERENCE TO *REVISED 1996 IPCC GUIDELINES*

Land-use category/ Chapter	Subcategory	C pool & non-CO_2 gases	Methods Section	Chapter 2 Method	Linkage to *Revised 1996 IPCC Guidelines*	Tier 1 Method
Livestock (Chapter 10)	Enteric Fermentation	CH_4 emissions	10.3	-	4A	⊕
	Manure Management	CH_4 emissions	10.4	-	4B	⊕
		N_2O emissions	10.5	-	4B	⊕
Managed soils (Chapter 11)	Soil Management	N_2O emissions	11.2	-	4D	⊕
	Liming	CO_2 emissions	11.3	-	_	⊕
	Urea Fertilization	CO_2 emissions	11.4	-	NE	⊕
Harvested wood products (Chapter 12)	Wood Products	C stock changes	Chapter 12	-	NE	⊕ [2]

The *Revised 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)

NE: not estimated under default method in the *1996 IPCC Guidelines*

NG – no guidance provided in the Guidelines

Notes for column "Tier 1 Method":

⊕ - Tier 1 methods and default parameters are available in the Guidelines.

0 = Tier 1 (default) assumption is that emissions are zero or in equilibrium; no methods and parameters are provided in the Guidelines.

1 = Tier 1 and default factors available only for organic soils.

2 = Tier 1 method available to estimate HWP variables which may be used to compute HWP Contribution to AFOLU.

3 = Tier 1 and default factors only available for perennial woody vegetation

NA – not applicable

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

No refinement.

References

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