CGE SUPPLEMENTARY TRAINING MATERIAL FOR THE TEAM OF TECHNICAL EXPERTS

Module 2.2d

Background material:

National greenhouse gas inventories – land use, land-use change and forestry sector

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ABBREVIATIONS

CH_4	methane
CO_2	carbon dioxide
DOM	dead organic matter
GHG	greenhouse gas
GPG LULUCF	Good Practice Guidance for Land Use, Land-Use Change and Forestry
IPCC	Intergovernmental Panel on Climate Change
LUCF	land-use change and forestry
LULUCF	land use, land-use change and forestry
N_2O	nitrous oxide
SOM	soil organic matter
TTE	team of technical experts

1.1. BACKGROUND AND COURSE OBJECTIVES

This material was developed within the context of the process for international consultation and analysis to further support the training for the team of technical experts (TTE) and to provide additional background knowledge and context.

This module, prepared as supplementary training material to module 2.2 on technical analysis of greenhouse gas (GHG) inventories, aims to provide an overview of the methods and science involved in estimating emissions from the land-use change and forestry (LUCF) or land use, land-use change and forestry (LULUCF) sector. This is intended for **those experts nominated to the UNFCCC roster of experts with no or limited prior knowledge and wishing to enhance their technical knowledge on national GHG inventories**.

It is drawn from the most recent Consultative Group of Experts (CGE) training materials on national GHG inventories for Parties not included in Annex I to the Convention (non-Annex I Parties), which are based on the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (hereinafter referred to as the Revised 1996 IPCC Guidelines), and *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (herein referred to as GPG LULUCF).

The information presented here should be further supplemented with that from the Revised 1996 IPCC Guidelines and the GPG LULUCF in order to address the complete length and breadth of science and methods involved in estimating GHG emissions and removals from the LUCF/LULUCF sector.

2. SECTOR OVERVIEW

2.1. INTRODUCTION

Land use, land-use change and forestry plays an important role as a source of emissions as well as a sink of removals from the atmosphere. Forest ecosystems contain a large part of the carbon stored on land, not only in the living biomass pool, but also in the soil pool and dead organic matter (DOM) pool. Other terrestrial systems, such as cropland and grassland, also play an important role in carbon dynamics related to land. Most of the carbon stocks of croplands and grasslands are found in the below-ground plant organic matter and soil. Although a part of the carbon exchange process between the atmosphere and terrestrial system may occur through natural processes, human activities, such as management practices and land-use changes, also affect changes in carbon stocks and the exchange process between the atmosphere and terrestrial system.

2.1.1. CATEGORIES OF EMISSIONS BY SOURCES AND REMOVALS BY SINKS

Both the Revised 1996 IPCC Guidelines (LUCF sector) and the GPG LULUCF cover the above mentioned anthropogenic carbon dioxide (CO_2) emissions by sources and removals by sinks. Some non-CO_2 emissions occur on land through land management practices and/or land-use change, however, the categorization system is slightly different.

The Revised 1996 IPCC Guidelines mainly focus on the main activities which are sources or sinks of CO_2. While, the GPG LULUCF covers not only the main activities, but also other activities, and therefore treats the whole national land and covers all carbon pools.

The Revised 1996 IPCC Guidelines classify the LUCF sector into four subsectors: changes in forest and other woody biomass stocks (5.A), forest and grassland conversion (5.B), abandonment of managed lands (5.C) and CO_2 emissions and removals from soil (5.D) (see table 1).

Table 1
Sectoral report for national greenhouse gas inventories

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Sheet)						
Greenhouse Gas Sources And Sink Categories	CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO
Total Land-Use Change and Forestry	(1)	(2)				
A Changes in Forest and Other Woody Biomass Stocks	(1)	(1)				
1 Tropical Forests						
2 Temperate Forests						
3 Boreal Forests						
4 Grassland Trends						
5 Other (please specify)						
B Forest and Grassland Conversion	(1)	(2)				
1 Tropical Forests						
2 Temperate Forests						
3 Boreal Forests						
4 Grassland Trends						
5 Other (please specify)						
C Abandonment of Managed Lands	(2)	(2)				
1 Tropical Forests						
2 Temperate Forests						
3 Boreal Forests						
4 Grassland Trends						
5 Other (please specify)						
D CO_2 Emissions and Removals from Soil	(2)	(2)				
E Other (please specify)						

The GPG LULUCF classifies the LULUCF sector into six broad land-use categories: forest land (5.A), cropland (5.B), grassland (5.C), wetlands (5.D), settlements (5.E), and other land (5.F). Each category is further divided into two subcategories, based on the status and recent history of the land use. The first subcategory is for the land that begins and ends an inventory period in the same land-use category, also called ‘remaining land’. The second subcategory is for the land converted from another land-use category within the past 20 years, also called ‘converted land’ (see table 2).

Table 2
Greenhouse gas source sink categories

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	Net CO_2 emissions/removals	CH_4	N_2O	NO_x	CO	NMVOC
	(Gg)					
Total Land-Use Categories						
A. Forest Land						
1. Forest Land remaining Forest Land						
2. Land converted to Forest Land						
B. Cropland						
1. Cropland remaining Cropland						
2. Land converted to Cropland						
C. Grassland						
1. Grassland remaining Grassland						
2. Land converted to Grassland						
D. Wetlands						
1. Wetlands remaining Wetlands (1)						
2. Land converted to Wetlands						
E. Settlements						
1. Settlements remaining Settlements (1)						
2. Land converted to Settlements						
F. Other Land						
1. Other Land remaining Other Land (2)						
2. Land converted to Other Land						
G. Other *(please specify)*						
Harvested Wood Products (1)						

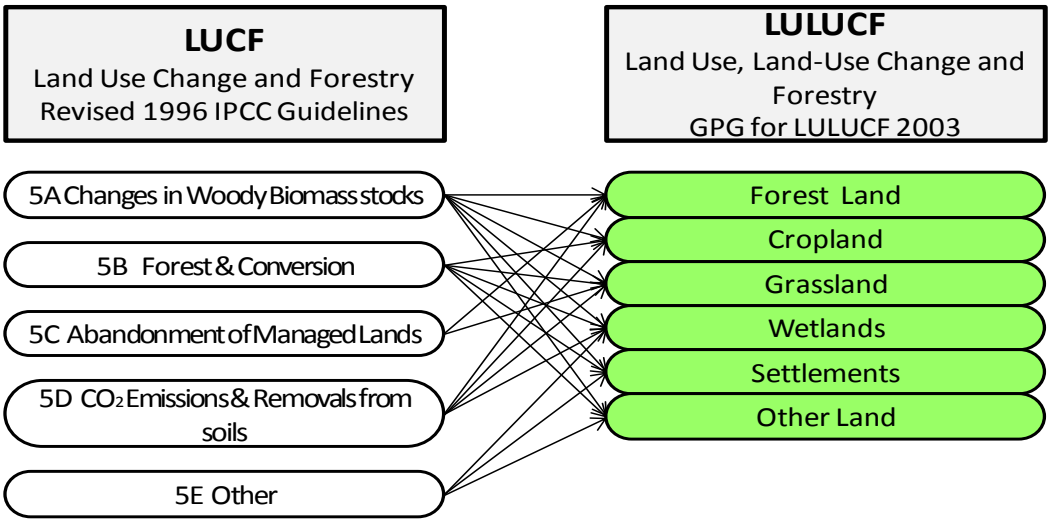
(1) Parties may decide not to prepare estimates for these categories, although they may do so if they wish.

(2) This land-use category is to allow the total of identified land area to match the national area.

The grey cells represent categories where emissions do not occur.

The mapping of LUCF with LULUCF categories is illustrated in figure 1.

Figure 1
Mapping of LUCF with LULUCF categories



Source: Based on Good Practice Guidance for Land Use, Land-Use Change and Forestry, Table 3.1.1.

2.2. CARBON POOLS

Carbon pools are the second broad classification used in the LUCF/LULUCF sector. Emissions and removals of CO_2 are basically considered through the change of carbon stock occurring in each pool. Table 3 provides a generic definition of these pools occurring in a terrestrial ecosystem, including aboveground biomass, below-ground biomass, deadwood, litter and soils.

The Revised 1996 IPCC Guidelines do not cover the below-ground biomass, deadwood and litter. Thus, these three carbon pools can only be estimated when a Party applies the GPG LULUCF.

Table 3
Definitions for terrestrial pools used in the LULUCF sector

DEFINITIONS FOR TERRESTRIAL POOLS USED IN CHAPTER 3		
Pool [2]		**Description (see also notes below in italics)**
Living Biomass	Above-ground biomass	All living biomass [3] above the soil including stem, stump, branches, bark, seeds, and foliage. Note: In cases where forest understorey 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 as specified in Chapter 5.
	Below-ground biomass	All living 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 any other diameter used by the country.
	Litter	Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country (for example 10 cm), lying dead, in various states of decomposition above the mineral or organic soil. This includes the litter, fumic, and humic layers. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.
Soils	Soil organic matter	Includes organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically.
Note: National circumstances may necessitate slight modifications to the pool definitions used here. Where modified definitions are used, it is good practice to report upon them clearly, to ensure that modified definitions are used consistently over time, and to demonstrate that pools are neither omitted nor double counted.		

Source: Good Practice Guidance for Land Use, Land-Use Change and Forestry, p. 3.15.

2.3. LUCF/LULUCF SECTOR EMISSION AND REMOVAL PROCESSES

2.3.1. GREENHOUSE GAS EMISSIONS AND REMOVALS OCCURRING IN THE LUCF/LULUCF SECTOR

In the LUCF/LULUCF sector, CO_2 emissions and removals occur through changes of the carbon stock in each carbon pool as a result of various human interventions. For instance, the absorption of CO_2 through growing plants results in an increase of the carbon stock in the living biomass; harvesting of trees results in a decrease of the carbon stock in living biomass; the mortality of trees left to decay on land results in a decrease of the carbon stock in the living biomass, but in an increase of the carbon stock in DOM. The increase of carbon in a pool is estimated as CO_2 removal, and the loss of carbon is estimated as CO_2 emission.

Some types of land conversion and/or management practices including fertilization, biomass burning, drainage of organic soil, lime application and mineralization of soil associated with land conversion generate flux type of GHG emissions in LUCF/LULUCF. These emissions generally occur depending on the activity or practice that took place.

A national GHG inventory for the LUCF/LULUCF sector includes both anthropogenic GHG emissions and removals. However, the GPG LULUCF concluded that the scientific community could not provide a practical methodology that could separate direct human-induced effects from indirect human-induced and natural effects for any broad range of LULUCF activities and circumstances. Thus, the current LUCF/LULUCF GHG inventory methodology applies an alternative approach aimed at identifying anthropogenic emissions and removals of ‘managed land proxy’, and considers all emissions and removals that occurred on managed land as anthropogenic. Managed land is defined as land where human interventions and practices have been applied to perform production, ecological or social functions.

2.3.2. CARBON STOCK CHANGES

Plants absorb CO2 from the atmosphere as they grow, and they store some of the carbon throughout their lifetime. Soils can also store CO_2, depending on how the soil is managed. This storage of carbon in plants and soils is called biological carbon sequestration. Because biological sequestration takes CO_2 out of the atmosphere, this is also called a greenhouse gas ‘sink’. This sequestrated carbon returns to the atmosphere based on decaying or burning which occurs following various activities, such as harvesting, fuelwood use, mortality of trees, etc. This is called a greenhouse gas ‘source’. Emissions or sequestration of CO_2 can occur as land-use change. Despite carbon sequestration occurring on land, some developing countries are net sources of emissions in the LUCF/LULUCF sector, because of the deforestation of large areas of forest land which are cleared, often for agricultural purposes or for settlements.

The carbon cycle includes changes in carbon stocks due to both continuous processes (i.e. growth, decay) and discrete events (i.e. disturbances like harvest, fire, insect outbreaks, land-use change and other events). Continuous processes can

affect carbon stocks in all areas in each year, while discrete events (i.e. disturbances) cause emissions and redistribute ecosystem carbon in specific areas (i.e. where the disturbance occurs) and in the year of the event.

2.3.3. NON-CARBON DIOXIDE EMISSIONS IN LUCF/LULUCF

Biomass burning represents the main non-CO_2 emission source in the LUCF/LULUCF sector in developing countries. Biomass burning generates methane (CH_4), nitrous oxide (N_2O), nitrogen oxides (NO_x), carbon monoxide (CO) and non-methane volatile organic compounds by oxidation of materials contained in the biogenic mass burnt in the process of incineration. See module 2.2a on the energy sector for more on the chemical features and physical processes of these gases and emissions.

Fertilization and drainage of organic soils generates N_2O emissions. The Revised 1996 IPCC Guidelines do not cover these sources, and the GPG LULUCF only covers these emissions on lands where the agriculture sector does not cover them (e.g. forest land, wetlands). See module 2.2c on the agriculture sector for further details on these sources.

Mineralization of soil associated with land conversion to cropland was introduced in the GPG LULUCF. The increase in N_2O emissions arises from the conversion of forest land, grassland and other land to cropland. This is a consequence of the enhanced mineralization (conversion to inorganic form) of soil organic matter (SOM) that normally takes place as a result of that conversion. The mineralization results not only in a net loss of soil carbon, and hence a net CO_2 emission, but also in associated conversion of nitrogen previously in the SOM to ammonium and nitrate. Microbial activity in the soil converts some of the ammonium and nitrate present to N_2O. Thus an increase in this microbial substrate caused by a net decrease in SOM can be expected to give an increase in net N_2O emissions.

Lime application through the application of carbonate containing lime (e.g. calcium carbonate ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$), to agricultural soils is a source of CO_2 emissions. A simplified explanation of the process is that, when carbonate lime is dissolved in the soil, the base cations (Ca++, Mg++) exchange with hydrogen ions (H+) on soil colloids (thereby reducing soil acidity), and the bicarbonate formed ($2HCO_3$) can react further to evolve into CO_2 and water (H_2O). Although the liming effect generally lasts a few years (after which lime is again added), depending on climate, soil and cropping practices, the Revised 1996 IPCC Guidelines account for CO_2 emissions assuming that all the added carbonate carbon occurs during the year of the application. Thus, the methodology is simply accounting for the amount of agricultural lime applied, times an emission factor, which varies slightly depending on the composition of the material added.

3. METHODS TO ESTIMATE GREENHOUSE GAS EMISSIONS FROM THE LUCF/LULUCF SECTOR

3.1. INTRODUCTION

3.1.1. GENERAL INFORMATION

In the Revised 1996 IPCC Guidelines and GPG LULUCF, methods are generally referred to as 'tiers', with higher tier methods being more advanced. The GPG LULUCF provides decision trees to help Parties in the selection of data and methods (i.e. tiers) for each individual category. These decision trees are intended to direct the Party to use the best method and data possible, given its national circumstances. It is **good practice** for Parties to utilize higher tier methods; with their associated more detailed data, in particular for key categories. Parties are, however, permitted some flexibility in applying these decision trees as long as the choices made by the Party result in estimates that are of equivalent quality to those described in the GPG LULUCF.

This flexibility is an important characteristic of the Revised 1996 IPCC Guidelines and the GPG LULUCF, because it recognizes that Parties have different national circumstances (e.g. availability of historical data). Although **good practice** is meant to direct Parties to use more rigorous methods and more detailed data, what is defined as 'good practice' can vary from Party to Party, depending on the national circumstances.

The GPG LULUCF defines GHG inventories consistent with good practice as those which contain **neither over- nor underestimates** so far as can be judged, and in which uncertainties are reduced as far as is practicable. It should be noted that conservative estimation concepts, such as intentionally estimating removals at a lower level in a certain range, are not in line with the principle of GHG inventory.

The GPG LULUCF further supports the development of inventories that are transparent, documented, consistent over time, complete, comparable, assessed for uncertainties, subject to quality control and assurance, efficient in the use of resources available to inventory agencies, and in which uncertainties are reduced as more reliable activity data and/or parameters or better information become available. This general concept is not mandatory for non-Annex I Parties under the current Conference of the Parties (COP) decisions. So, this concept should only be treated as an ideal goal of GHG inventory for non-Annex I Parties on a voluntary basis.

3.1.2. THREE METHODOLOGICAL TIERS IN LUCF/LULUCF

Tier 1

This applies the basic method provided in the Revised 1996 IPCC Guidelines and the default emission factors (EFs) (updated in GPG LULUCF). It includes other land uses and pools whose default emissions or removals were assumed to be 'zero'.

Tier 2

This can use the same approach as tier 1, but applies EFs and activity data which are defined by the country. It can also apply stock change methodologies based on country-specific data.

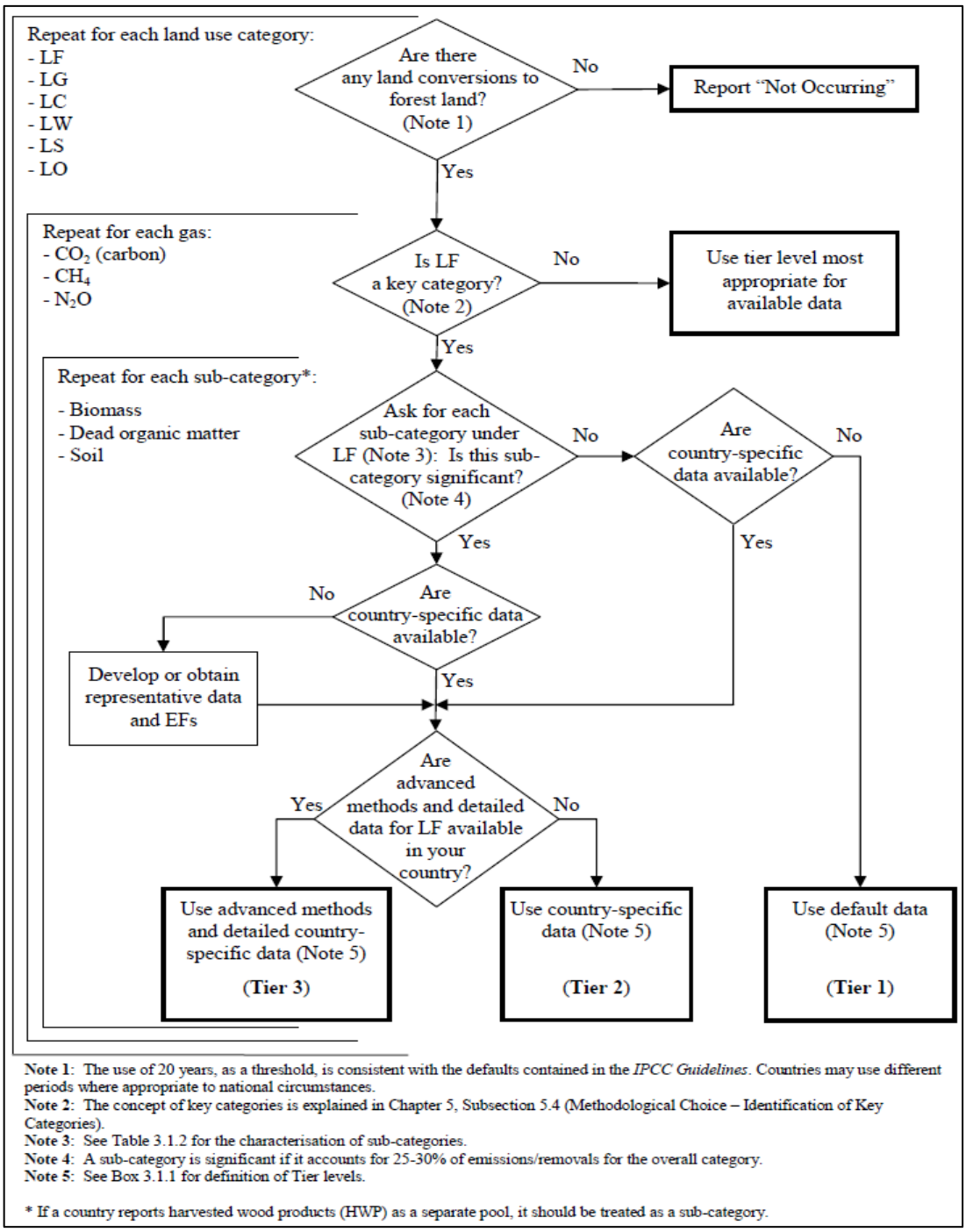
Tier 3

These are higher order methods, including models and inventory measurements.

3.1.3. DECISION TREE FOR IDENTIFYING THE APPROPRIATE TIER

The GPG LULUCF provides a decision tree for identification of the appropriate tier-level for land converted to another land-use category, to help Parties select the appropriate tier based on their national circumstances (figure 2).

Figure 2
Decision tree for identification of appropriate tier level for land converted to another land-use category (example given for land converted to forest land, LF)



Note 1: The use of 20 years, as a threshold, is consistent with the defaults contained in the *IPCC Guidelines*. Countries may use different periods where appropriate to national circumstances.
Note 2: The concept of key categories is explained in Chapter 5, Subsection 5.4 (Methodological Choice – Identification of Key Categories).
Note 3: See Table 3.1.2 for the characterisation of sub-categories.
Note 4: A sub-category is significant if it accounts for 25-30% of emissions/removals for the overall category.
Note 5: See Box 3.1.1 for definition of Tier levels.

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

Source: Good Practice Guidance for Land Use, Land-Use Change and Forestry, p. 1.7.

3.2. OVERVIEW OF THE LUCF SECTOR (REVISED 1996 IPCC GUIDELINES)

The inventory methods for LUCF in the Revised 1996 IPCC Guidelines focus on the most important land-use and management changes that result in CO_2 emissions and removals, including four broad categories.

Changes in forest and other woody biomass stocks

The 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. Natural undisturbed forests, where they exist and are in equilibrium, should not be considered and can be excluded from national inventory calculations.

Forest and grassland conversion

Conversion of forest and grassland 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.

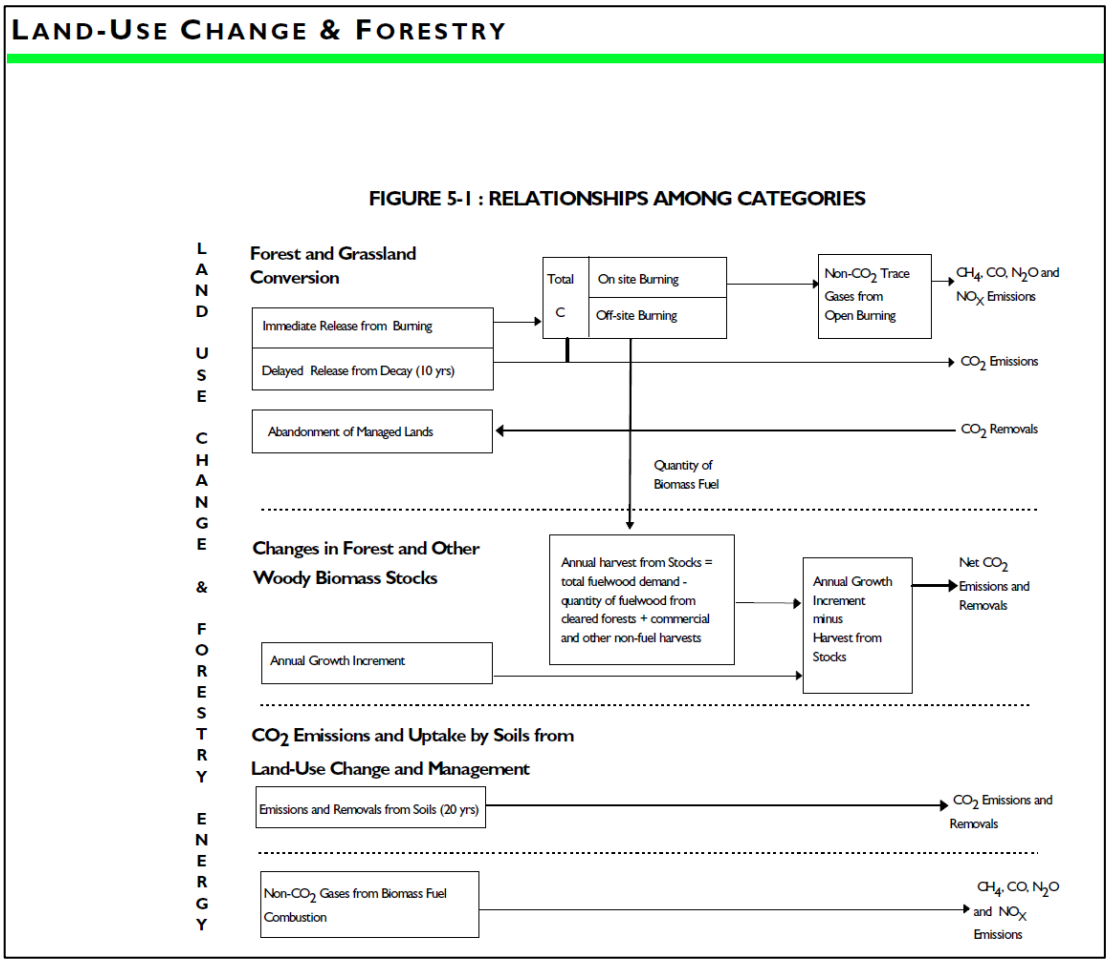
Abandonment of managed lands (croplands, pastures, plantation forests or other managed lands)

Abandoned lands often accrue carbon in biomass and soils over time, particularly if the conditions approach those found in natural grasslands or forests.

CO_2 emissions and removals from soils

Changing management can alter the CO_2 emissions and removals from soils, particularly through the adoption of conservation practices or increasing crop and forage production.

Figure 3
Relationships among categories



Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 5.10.

Table 4 shows a summary of the methodologies provided in the Revised 1996 IPCC Guidelines. The total LUCF sector net emissions and removals are shown as the summed up estimation of each category.

Table 4
Methodologies provided in the Revised 1996 IPCC Guidelines

Above-ground biomass	Yes	Yes	Yes	NA
Soil organic carbon	NA	NA	NA	Yes
Lime application	NA	NA	NA	Yes
Biomass burning		Yes		NA

Abbreviation: NA = not applicable.

3.3. OVERVIEW OF THE LULUCF SECTOR (GPG LULUCF)

The emissions and removals of CO_2 for the LULUCF sector, based on changes in ecosystem carbon stocks, are estimated for each land-use category (including both land remaining in a land-use category as well as land converted to another land use).

3.3.1. FOREST LAND (5.A)

Forest land includes all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, subdivided into managed and unmanaged, as well as by ecosystem type as specified in the Revised 1996 IPCC Guidelines. It also includes systems with vegetation that currently fall below, but are expected to exceed, the threshold of the forest land category. Methodologies for all five carbon pools are provided, for both land remaining forest land and land converted to forest land. A country does not have to estimate GHG emissions which occurred on unmanaged forest land. The forest land category includes the following estimations:

- Carbon stock change in living biomass;
- Carbon stock change in deadwood, litter and net annual change in carbon stock in DOM;
- Carbon stock change in mineral soils and organic soils and net annual change in carbon stock in soils;
- Carbon stock change and GHG emissions and removals associated with changes in biomass and soil organic carbon on forest land and lands converted to forest land;
- N_2O emissions from fertilization on forest land;
- (Voluntary) N_2O emissions from drainage of organic soil on forest land.

3.3.2. CROPLAND (5.B)

Cropland includes arable and tillage land, and agroforestry systems where vegetation falls below the threshold used for the forest land category, consistent with the selection of national definitions. Generally, cropland is considered as managed. Soils represent the most dominant carbon pool in cropland. For the living biomass pool, only carbon stock change in perennial woody crop is covered. DOM is not addressed in tier 1 and 2. It is necessary to recall that non-CO_2 emissions occurring through agriculture practices, such as fertilization and biomass residue burning, are covered under the agriculture sector. The LULUCF sector focuses only on CO_2 emissions and removals. The cropland category includes the following estimations:

- Carbon stock changes in living biomass (perennial woody crops);
- Carbon stock changes in mineral soils;
- CO_2 emissions from drainage of organic soils;

- CO_2 emissions from lime application;
- Carbon stock changes in living biomass and mineral soils due to land converted to cropland;
- N_2O from mineralization of soil associated with land conversion to cropland based on the amount of carbon loss from soil calculated in land conversion with a carbon to nitrogen ratio.

3.3.3. GRASSLAND (5.C)

Grassland includes rangelands and pasture land that is not considered as cropland. It also includes systems with vegetation that fall below the threshold used in the forest land category and are not expected to exceed, without human intervention, the threshold used in the forest land category. The category also includes all grassland from wild lands to recreational areas, as well as agricultural and silvi-pastural systems, subdivided into managed and unmanaged, consistent with national definitions. Carbon stocks in grasslands are influenced by human activities and natural disturbances, including harvesting of woody biomass, rangeland degradation, grazing, fires, rehabilitation, pasture management, etc.; below-ground biomass, including root biomass and soil organic matter, dominates grasslands. The grassland category includes the following estimations:

- Carbon stock changes in living biomass;
- Carbon stock changes in mineral soils;
- CO_2 emissions from drainage of organic soils;
- Non-CO_2 emissions from grassland fire.

3.3.4. WETLANDS (5.D)

Wetlands include land that is covered or saturated by water for all or part of the year and that does not fall into forest and other categories; it is necessary to distinguish between managed and unmanaged. It includes reservoirs, as a managed subdivision, and natural rivers and lakes, as unmanaged subdivisions. Wetlands have two broad subcategories, peat extraction and flooded land. Although CO_2, CH_4 and N_2O emissions may occur in wetlands due to activities such as drainage of peat soil, limited methodologies are provided in the GPG LULUCF. Methodologies for estimating wetlands remaining wetlands are given in appendix 3a.3 to the GPG LULUCF, and the methodology for living biomass carbon stock change from land converted to wetlands is in the main body of the GPG LULUCF. As a result, the only required estimation of emissions from wetlands is for the living biomass loss due to land converted to wetlands (flooded land). The wetlands category includes the following estimations:

- Carbon stock changes in living biomass due to land conversion to wetlands;
- (Voluntary) N_2O emissions from peat land drainage and CH_4 emissions from flooded land.

3.3.5. SETTLEMENTS (5.E)

Settlements include all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with the selection of national definitions. In this category, the land remaining settlement is treated as voluntary estimation and only the living biomass carbon stock change estimation method is covered. The settlements category includes the following estimations:

- Carbon stock changes in living biomass due to land conversion to settlements;
- (Voluntary) Carbon stock changes in living biomass of urban trees.

3.3.6. OTHER LAND (5.F)

Other land includes bare soil, rock, ice and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available. The other land remaining other land category is treated as the land where carbon stock changes cannot occur, and changes in carbon stocks and non-CO_2 emissions and removals need not be assessed. The other land category includes the following estimation:

- Carbon stock changes in living biomass and soil due to land conversion to other land.

3.3.7. SUMMARY OF THE METHODOLOGIES PROVIDED

Table 5 shows a summary of the methodologies provided in the GPG LULUCF. Some methodologies are given in appendixes to chapter 3 of the GPG LULUCF. This means that the relevant methods of estimation were in need of further improvement at the time of the adoption of the GPG LULUCF, which is why they are treated as voluntary calculation.

Table 5
Methodologies covered in GPG LULUCF

Remaining land	Living biomass	Yes	Yes	Yes	(Partly)	(Yes)	NA
	DOM	Yes	No	No	No	No	NA
	Soil organic carbon	Yes	Yes	Yes	(Partly)	No	NA
Converted Land	Living biomass	Yes	Yes	Yes	Yes	Yes	Yes
	DOM	Yes	No	No	No	No	No
	Soil organic carbon	Yes	Yes	Yes	No	No	Yes
N_2O from fertilization		Yes	Covered in agr. sector	Covered in agr. sector	(Yes)	No	NA
N_2O from drainage		(Yes)	Covered in agr. sector	Covered in agr. sector	(Yes)	No	NA
Nitrogen mineralization		NA	Yes	Yes	NA	NA	NA
Lime application		NA	Yes	Yes	NA	NA	NA
Biomass burning		Yes	Covered in agr. sector	Yes	NA	(Yes)	NA

Yes = methodology exists, No = methodology does not exist, NA = methodology is not applicable here, ( ) = the relevant methodology is provided in an appendix and treated as voluntary reporting.

3.4. CARBON STOCK CHANGE IN LIVING BIOMASS: DEFAULT METHOD (TIER 1, 2)

Carbon stock change in living biomass is calculated by multiplying the difference in oven dry weight of biomass increments and losses with the appropriate carbon fraction. Two methods are provided in the GPG LULUCF, one is the 'default method' (sometimes referred to as the 'gain–loss method') already mentioned in the Revised 1996 IPCC Guidelines, and the other one is the stock change method introduced by the GPG LULUCF.

The default method requires the biomass carbon loss to be subtracted from the biomass carbon increment (gain) for the reporting year. This method is applicable to the living biomass calculation on forest land and other land uses (equation 1).

Equation 1
Stock change

$$\Delta C = \Delta C_{gain} - \Delta C_{loss}$$

Gains can be attributed to growth (increase of biomass) and to transfer of carbon from another pool (e.g. transfer of carbon from the live biomass carbon pool to the DOM pool due to harvest or natural disturbances). Losses can be attributed to transfers of carbon from one pool to another (e.g. the carbon in the slash during harvesting represents a loss from the aboveground biomass pool), or emissions due to decay, harvest, fuelwood gathering and natural losses.

In forest land, annual growth per area (G_w: t-dry matter/ha/year) is estimated by multiplying (i) net increment in volume (IV: m^3/ha/year), (ii) wood density (D: dry matter/m^3), and (iii) the biomass expansion factor for conversion of annual net increment (including bark) to aboveground tree biomass increment (BEF1, dimensionless). The Revised 1996 IPCC Guidelines only include the aboveground biomass, while the GPG LULUCF introduces a parameter of root to shoot ratio (R), and expanding growth ratio, including both above- and below-ground biomass (G_{total}). The total gain is estimated by area (A, ha), increment of biomass (G_{total}), and carbon fraction (CF, default = 0.5) (equation 2).

Equation 2
Annual growth per area

$$G_{total} = G_w \times (1 + R), \qquad G_w = I_V \times D \times BEF_1, \qquad Gain = A \times G_{total} \times CF$$

In forest land, the total loss is the sum of losses from commercial roundwood felling, fuelwood gathering and other losses. The Revised 1996 IPCC Guidelines focus on harvesting and fuelwood gathering, and the GPG LULUCF includes other losses. The data from harvesting and fuelwood gathering is usually obtained as a volume (V). The carbon loss is estimated by multiplying (i) the wood density (D), (ii) the biomass expansion factor for converting volumes of extracted roundwood to total aboveground biomass (including bark) (BEF_2), and (iii) the carbon fraction (CF) with the volume data (equation 3).

Equation 3
Total loss

$$Loss = V \times D \times BEF_2 \times CF$$

The default method is applicable for all tiers. The default values of parameters referred to above are provided in stratified categories, such as forest type, tree type and climate zone, etc. A party should select (tier 1) and/or develop (tier 2) the relevant parameters from the appropriate category. Equation 4 illustrates the Revised 1996 IPCC Guidelines basic estimation method for carbon stock change in aboveground biomass.

Equation 4
Estimation method for carbon stock change in aboveground biomass

(1)	hectares of land in a particular category (e.g., plantations) x average annual growth per hectare in biomass = gross annual growth increment. *total biomass increment is the sum of all relevant categories.*
(2)	total harvest by category (including fuelwood gathering) x expansion ratio to treat slash = gross annual biomass loss. *total harvest and other biomass loss is the sum of all relevant categories of harvest.*
(3)	total annual growth increment - total annual biomass loss = annual biomass change (positive or negative).

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, p. 5.19.

The Revised 1996 IPCC Guidelines contain the default assumption that all carbon in harvested biomass is oxidized in the removal year, so the carbon contained in wood products is treated as already emitted to the atmosphere even if, in reality, it still remains as carbon stock. This assumption provides the flexibility to include carbon storage in harvested wood products (HWP) if existing stocks can be demonstrated. The GPG LULUCF provides estimation methods for HWP, which can be applied by a Party on a voluntary basis.1

3.5. CARBON STOCK CHANGE IN LIVING BIOMASS: STOCK CHANGE METHOD (TIER 2)

The alternative stock-based approach, also known as the 'stock change method', was introduced in the GPG LULUCF. It can be used where carbon stocks in relevant pools are measured at two points in time to assess carbon stock changes. The stock change method for living biomass requires biomass carbon stock inventories for a given forest area at two points in time. The biomass change is the difference in the biomass between time t_2 and time t_1, divided by the number of years between the inventories.

To estimate the annual change in carbon stocks in biomass in forest land remaining forest land, one must multiply (i) merchantable volume (V, m^3/ha), (ii) basic wood density (t-d_m/m^3), (iii) the biomass expansion factor for conversion of merchantable volume to aboveground tree biomass (BEF_2), (iv) root to shoot ratio (R), and (v) carbon fraction (CF, t-C/t-d_m) (see equation 5). This method requires country-specific volume inventory data for forests and therefore excludes any tier 1 approach.

[1] GPG LULUCF, appendix 3a.1.

Equation 5
Annual change in carbon stocks in living biomass in forest land remaining forest land (stock change method)

ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN FOREST LAND REMAINING FOREST LAND (STOCK CHANGE METHOD)

$$\Delta C_{FF_{LB}} = (C_{t_2} - C_{t_1}) / (t_2 - t_1)$$

and

$$C = [V \bullet D \bullet BEF_2] \bullet (1 + R) \bullet CF$$

Source: IPCC Good Practice Guidance for LULUCF, p. 3.24.

If the carbon stock changes are estimated on a per hectare basis, then the value is multiplied by the total area within each stratum to obtain the total stock change estimate for the pool. In some cases, the activity data may be in the form of country totals (e.g. harvested wood) in which case the stock change estimate for that pool is estimated directly from the activity data, after applying appropriate factors to convert to units of carbon mass.

3.6. CARBON STOCK CHANGE IN LIVING BIOMASS IN CONVERSION TO A NEW CATEGORY

The methods for the estimation of emissions and removals of carbon resulting from land-use conversion from one land-use category to another can include conversions from non-forest to forest land, cropland and forest land to grassland, and grassland and forest land to cropland, and any other type of conversion among land uses. The CO_2 emissions and removals from land converted to a new land-use category include annual changes in carbon stocks in aboveground biomass and below-ground biomass.[2]

3.6.1. LAND CONVERTED TO FOREST LAND

The Revised 1996 IPCC Guidelines provide a tier 1 default approach for the changes in carbon stocks in living biomass on land converted to forest through artificial and natural regeneration (abandonment of managed land). This tier 1 approach focuses on the annual increase of carbon stock due to the growth of biomass in converted land (CGROWTH) and the decrease of carbon in biomass due to losses from harvesting, fuelwood gathering, etc. So, the methodology is very similar to the default method for the land remaining in the same category. The approach can be applied even when previous land uses are not known, which may be the case if areas are estimated using GPG LULUCF approach 1 or 2 (see section 4.2 of this document).

[2] Belowground biomass and DOM are included only when the GPG LULUCF is applied.

Equation 6
Annual change in carbon stocks in living biomass in land converted to forest land (tier 1)

ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO FOREST LAND (TIER 1)

$$\Delta C_{LF_{LB}} = \Delta C_{LF_{GROWTH}} - \Delta C_{LF_{LOSS}}$$

Source: IPCC Good Practice Guidance for LULUCF, p. 3.51.

Equation 7 illustrates the Revised 1996 IPCC Guidelines basic estimation method for net change in aboveground biomass.

Equation 7
Estimation method for net change in aboveground biomass

average annual land clearing over the period (default of 10 years)

x

the average quantity of aboveground dry biomass per hectare remaining on site as slash but not burned (either oxidised or converted to charcoal)

x

carbon content of dry biomass

=

flux in the Inventory Year from historical land clearing of the aboveground vegetation

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, p. 5.32.

The tier 2 approach includes one additional factor about the carbon stock change occurring in the process of conversion (CCONVERSION). CCONVERSION is estimated by comparing the carbon stock of land immediately before conversion with the same land immediately after conversion to forest land (equation 8).

Equation 8
Annual change in carbon stock in living biomass in land converted to forest land (tier 2)

ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO FOREST LAND (TIER 2)

$$\Delta C_{LF_{LB}} = \Delta C_{LF_{GROWTH}} + \Delta C_{LF_{CONVERSION}} - \Delta C_{LF_{LOSS}}$$

Source: IPCC Good Practice Guidance for LULUCF, p. 3.53.

3.6.2. LAND CONVERTED TO CROPLAND

The tier 1 method for estimating carbon stocks in land converted to cropland follows the approach in the Revised 1996 IPCC Guidelines, where the amount of biomass cleared for cropland is estimated by multiplying the forest area converted in one year by the average carbon stock in biomass in the forest prior to the conversion. Under

the GPG LULUCF, all land conversion to cropland is included, so each initial land use before conversion includes, but is not limited to, forests and grassland. The default assumption is that carbon stocks immediately following conversion are equal to zero. This enables countries to take into account land-use transitions where some, but not all, vegetation from the original land use is removed.

Equation 9
Annual change in carbon stocks in living biomass in land converted to cropland

ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO CROPLAND

$$\Delta C_{LC_{LB}} = A_{Conversion} \bullet (L_{Conversion} + \Delta C_{Growth})$$

$$L_{Conversion} = C_{After} - C_{Before}$$

Source: IPCC Good Practice Guidance for LULUCF, p. 3.85.

Under tier 2, it is a good practice to apportion carbon losses to burning and decay processes, if applicable. Emissions of CO_2 occur as a result of burning and decay in land-use conversions. In addition, non-CO_2 trace gas emissions occur as a result of burning of biomass. By partitioning losses to burning and decay, countries can also calculate non-CO_2 trace gas emissions from burning. The Revised 1996 IPCC Guidelines provide step-by-step instructions for estimating carbon removals from the burning and decay of biomass on-site and off-site, and for estimating non-CO_2 trace gas emissions from burning (pages 5.7-5.17).

Equation 10
Carbon losses from biomass burning, on-site and off-site

CARBON LOSSES FROM BIOMASS BURNING, ON-SITE AND OFF-SITE

$$L_{burn\ onsite} = \Delta C_{conversion} \bullet \rho_{burned\ on\ site} \bullet \rho_{oxid}$$

$$L_{burn\ offsite} = \Delta C_{conversion} \bullet \rho_{burned\ off\ site} \bullet \rho_{oxid}$$

Source: IPCC Good Practice Guidance for LULUCF, p. 3.86.

3.7. CARBON STOCK CHANGE IN MINERAL SOILS

For mineral soils, the estimation method is based on changes in soil carbon stocks over a finite period following changes in management that impact soil carbon, as shown in equation 11. Previous soil C carbon stocks ($SOC_{(0-T)}$) and soil carbon stocks in the inventory year (SOC_0) for the area of a cropland system in the inventory are estimated from reference carbon stocks (SOCREF) and stock change factors (FLU, FMG, FI), applied for the respective time points. Annual rates of emissions (source) or removals (sink) are calculated as the difference in stocks (over time) divided by the inventory time period. The default time period is 20 years.

The Revised 1996 IPCC Guidelines provide default values for all parameters for soil carbon stocks (SOCREF, FLU, FMG, FI), and the GPG LULUCF slightly updated these default values. The reference carbon stock value (SOCREF) should be selected based on the climate and soil type, for each area of land being inventoried.

The Party identifies the type of cropland use (long-term cultivated, paddy rice, set-aside) (FLU) at the beginning of the inventory period (e.g. 20 years ago) and the inventory year, together with tillage (FMG) and carbon input levels (FI). Then soil carbon stocks for the two time periods SOC_0 and $SOC_{(0-T)}$ are estimated and the average annual change in the soil carbon stock for the area over the inventory period is also estimated using the difference of these two soil carbon stocks divided by the transition period (default is 20 years).

Equation 11
Annual change in carbon stocks in mineral soils for a single cropland system

ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS FOR A SINGLE CROPLAND SYSTEM

$$\Delta C_{CC_{Mineral}} = [(SOC_0 - SOC_{(0-T)}) \bullet A] / T$$

$$SOC = SOC_{REF} \bullet F_{LU} \bullet F_{MG} \bullet F_I$$

Source: IPCC Good Practice Guidance for LULUCF, p. 3.75.

This calculation needs at least two sets of time series data on land-use area with soil type. Sometimes soil carbon stock values are directly identified based on country-specific measurement data (tier 2) or carbon stock changes are estimated based on model estimation (tier 3).

The equation is applicable to both management changes under the remaining land categories as well as land-use changes under the converted land categories. Carbon stock change in soils on land converted to other land use is estimated by comparing carbon stocks in the previous land use before conversion, and the current land use after conversion divided by the transition period. The basic default assumption of this soil calculation is that the soil organic matter will reach a new equilibrium 20 years after the change, and land-use changes have a linear impact on soil organic matter for 20 years before a new equilibrium is reached.

3.8. EMISSIONS FROM ORGANIC SOILS

The basic methodology for estimating carbon emissions from organic (e.g. peat-derived) soils is to assign an annual emission factor that estimates the losses of carbon following drainage. Drainage stimulates oxidation of organic matter previously built up under a largely anoxic environment. Specifically, the area of drained and managed organic soils under each climate type is multiplied by the associated emission factor to derive an estimate of annual CO_2 emissions (source), as presented in equation 12.

Equation 12
CO_2 emissions from cultivated organic soils in cropland remaining cropland

CO_2 EMISSIONS FROM CULTIVATED ORGANIC SOILS IN CROPLAND REMAINING CROPLAND

$$\Delta C_{CC_{Organic}} = \sum_c (A \bullet EF)_c$$

Source: IPCC Good Practice Guidance for LULUCF, p. 3.79.

The default emission factor is provided in each climatic zone (cool temperate, warm temperate and tropical) and each land use (cropland, pasture, forest land). The party must select (tier 1) or develop (tier 2) EFs of appropriate climatic zone and land use. The area of organic soil should be stratified in the climatic zone and land used, if necessary. The GHG emissions only occur when organic soil area is used as oxidized status, such as cultivation and drainage, so the conserved organic soil area as natural state does not have to be treated as the activity data area of cultivated organic soils. There is no distinction between remaining land and converted land in this estimation.

The LUCF/LULUCF sector estimation of this source covers CO_2 emissions only. N_2O emissions from the same activity are covered under the agricultural soil category from the agriculture sector. The CH_4 emission estimation methodology is neither provided in the Revised 1996 IPCC Guidelines nor in the GPG LULUCF. CH_4 appears for the first time in the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement) and this supplementary guidance is not mandatory for non-Annex I Parties.

3.9. NON-CARBON DIOXIDE EMISSIONS

Non-CO_2 emissions are derived from a variety of sources, including emissions from soils and combustion of biomass (deadwood and litter – higher Tier only). The estimate of non-CO_2 gases are usually estimated using an emission rate from a source directly to the atmosphere represented as EF, and activity data such as area (e.g. area burnt) or mass (e.g. amount of fertilizer applied, biomass burnt). Many of the emissions of non-CO_2 gases are either associated with a specific land use or are typically estimated from national-level aggregate data.

Emission = A * EF

- Emission = non-CO_2 emissions, tonnes of the non-CO_2 gas
- A = activity data relating to the emission source (can be an area, or biomass unit, depending on the source type)
- EF = emission factor for a specific gas and source category, tonnes per unit of A

4. SECTOR SPECIFIC ISSUES

4.1. LAND USE DEFINITIONS

When applying the GPG LULUCF, information on how the country defines the land-use categories should be clearly explained. Although the GPG LULUCF provides a general indication of how the six land-use categories can be considered, the country will still use its own national definition of these categories, which may, of course, refer to internationally accepted definitions, such as those of the Food and Agriculture Organization of the United Nations (FAO). The six land-use categories are a mixture of land cover (e.g. forest land, grassland, wetlands) and land use (e.g. cropland, settlements) classes. For convenience, they are referred to as 'land-use categories' in the GPG LULUCF. The general definition of each land-use category is explained above in section 3.3 of this document.

4.2. APPROACHES FOR LAND REPRESENTATION

When applying the GPG LULUCF, identifying land conversion is a fundamental issue in the LULUCF sector. There are three approaches for land representation: approach 1, 2 and 3. A country is allowed to use all three approaches for identifying the land conversion and the GPG LULUCF suggests that there is no hierarchy among these three approaches. In reality, more explicit data is available in approach 2 than approach 1, and approach 3 is sometimes necessary when using a model and higher tier estimation.

Approach 1

This is probably the most common approach used for preparing estimates of emissions and removals with the Revised 1996 IPCC Guidelines for categories 5.A–5.E. The basic methodology of this approach is to compare the area of each land-use category in two time points and to derive the land-use change area in each land-use category. It often uses area datasets likely to have been prepared for other purposes, such as forestry or agricultural statistics.

Table 6
Example of approach 1: available land- use data with complete territorial coverage

EXAMPLE OF APPROACH 1: AVAILABLE LAND -USE DATA WITH COMPLETE TERRITORIAL COVERAGE								
Time 1			**Time 2**			**Land-Use Change between Time 1 and Time 2**		
F	=	18	F	=	19	Forest	=	+1
G	=	84	G	=	82	Grassland	=	-2
C	=	31	C	=	29	Cropland	=	-2
W	=	0	W	=	0	Wetlands	=	0
S	=	5	S	=	8	Settlements	=	+3
O	=	2	O	=	2	Other land	=	0
Sum	=	*140*	*Sum*	=	*140*	*Sum*	=	*0*
Note: F = Forest land, G = Grassland, C = Cropland, W = Wetlands, S = Settlements, O = Other land. Numbers represent area units (Mha in this example).								

Source: Good Practice Guidance for Land Use, Land-Use Change and Forestry, p. 2.8.

Approach 2

The essential feature of approach 2 is that it provides a national or regional-scale assessment of, not only the losses or gains in the area of specific land categories, but also of what these changes represent (i.e. changes from and to a category). Thus, approach 2 includes more information on changes between categories. Tracking land-use changes in this explicit manner will normally require the estimation of initial and final land-use categories, as well as of total area of unchanged land by category. The final result of this approach can be presented as a non-spatially explicit land-use change matrix.

Table 7
Simplified land-use change matrix for example approach 2

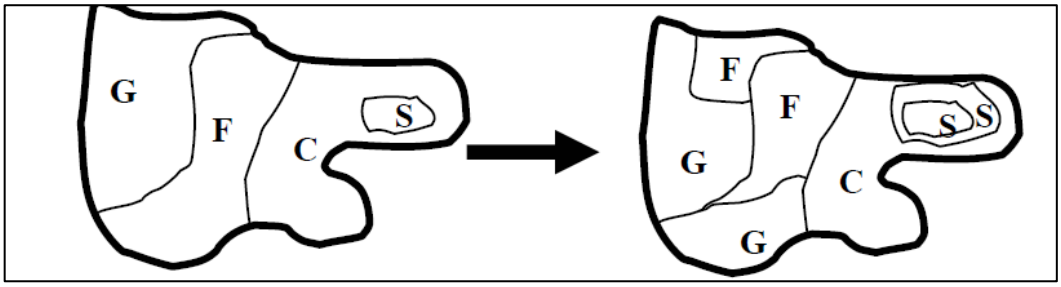
SIMPLIFIED LAND-USE CHANGE MATRIX FOR EXAMPLE APPROACH 2							
Land-Use Change Matrix							
Initial / Final	**F**	**G**	**C**	**W**	**S**	**O**	***Final sum***
F	**15**	3	1				*19*
G	2	**80**					*82*
C			**29**				*29*
W							
S	1	1	1		**5**		*8*
O						**2**	*2*
Initial sum	*18*	*84*	*31*		*5*	*2*	*140*
Note: F = Forest land, G = Grassland, C = Cropland, W = Wetlands, S = Settlements, O = Other land Numbers represent area units (Mha in this example). There is no Wetlands in this example. Blank entry indicates no land use change.							

Source: Good Practice Guidance for Land Use, Land-Use Change and Forestry, p. 2.11.

Approach 3

This requires spatially explicit observations of land use and land-use change. The data may be obtained either by sampling of geographically located points, a complete tally (wall-to-wall mapping), or a combination of the two.

Figure 4
Spatial observation



Source: Good Practice Guidance for Land Use, Land-Use Change and Forestry, p. 2.13.

4.3. ACCOUNTING FOR CARBON DIOXIDE AND NON-CARBON DIOXIDE EMISSIONS FROM BIOMASS USE FOR ENERGY AND WASTE

Biogenic CO_2 emissions both from annual crop biomass and perennial woody biomass are to be accounted for in the LUCF/LULUCF sector. For annual crops, the increase in biomass stocks in a single year is assumed equal to the biomass losses from harvest and mortality in that same year – thus there is no net accumulation of biomass carbon stocks, and CO_2 emissions from combustion are to be included in the loss process of this balanced estimation. For perennial woody biomass including forest, the default assumption of tree harvesting assumes an instantaneous oxidation of the carbon at the time of harvesting, so the CO_2 emissions occurring from the combustion are already accounted for at the time of harvesting under the LUCF/LULUCF sector.

However, non-CO_2 emissions from biomass burning should be estimated as non-CO_2 gases having different or higher global warming potential. The appropriate reporting categories of non-CO_2

emissions are shown in table 8. The TTE should ensure that there is no double counting and no significant omitting of emissions from biomass burning.

Table 8
Appropriate categories of reporting non-CO_2 gas emissions from biomass burning

Activity	Sector for reporting
Agriculture residue burning	Agriculture
Prescribed burning on savannah	Agriculture
Forest fire (on site)	LUCF/LULUCF
Bio-energy	Energy