3.2 FOREST LAND

This section of the *Guidance* provides methods for estimating carbon stock changes and greenhouse gas emissions and removals associated with changes in biomass and soil organic carbon on forest lands and lands converted to forest land. It is consistent with the approach in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (*IPCC Guidelines*) whereby the annual change in biomass is calculated from the difference between biomass growth and loss terms. The *Guidance*:

Addresses the five carbon pools identified in Section 3.1;

- Links biomass and soil carbon pools for the same land areas at the higher tiers;
- Includes emissions of carbon on managed lands due to natural losses caused by fire, windstorms, pest and disease outbreaks;
- Provides methods to estimate non-CO_2 greenhouse gas emissions; and
- Should be used together with the approaches for obtaining consistent area data described in Chapter 2.

Section 3.2 is organised into two parts. Section 3.2.1, the first section, covers the methodology to estimate changes in carbon stocks in five pools on forest areas which have been forest for at least the past 20 years[1]. The second section, Section 3.2.2, addresses changes in carbon stocks on lands converted more recently to forest. Section 3.2.1 describes how the decision tree in Figure 3.1.1, given in Section 3.1.6, should be used to facilitate choices on tier level for carbon pools and non-CO_2 gases.

As stated in the *IPCC Guidelines*, natural, undisturbed forests should not be considered either an anthropogenic source or sink and are excluded from national inventory estimation. This chapter therefore provides guidance on estimating and reporting of anthropogenic sources and sinks of greenhouse gases for managed forests only. The definition of managed forest is discussed in Section 3.1.2.1. Definitions at the national level should be applied consistently over time and cover all forests subject to periodic or ongoing human intervention, including the full range of management practices from commercial timber production to non-commercial purposes.

The *IPCC Guidelines* contain the default assumption that all carbon in harvested biomass is oxidised in the removal year, but gives flexibility to include carbon storage in harvested wood products (HWP) if existing stocks can be shown to be increasing. Accounting for HWP is also under consideration by the SBSTA. Pending the outcome of negotiations, estimation methods for HWP are discussed in a separate section (Appendix 3a.1). This indicates the state of methodological development and does not affect the advice in the *IPCC Guidelines*, or prejudge the outcome of the negotiations referred to.

3.2.1 Forest Land Remaining Forest Land

Greenhouse gas inventory for the land-use category 'Forest land Remaining Forest land (FF)' involves estimation of changes in carbon stock from five carbon pools (i.e. aboveground biomass, belowground biomass, dead wood, litter, and soil organic matter), as well as emissions of non-CO_2 gases from such pools. The summary equation, which estimates the annual emissions or removals from FF with respect to changes in carbon pools is given in Equation 3.2.1.

EQUATION 3.2.1
ANNUAL EMISSIONS OR REMOVALS FROM FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF} = (\Delta C_{FF_{LB}} + \Delta C_{FF_{DOM}} + \Delta C_{FF_{Soils}})$$

Where:

ΔC_{FF} = annual change in carbon stocks from forest land remaining forest land, tonnes C yr^{-1}

$\Delta C_{FF_{LB}}$ = annual change in carbon stocks in living biomass (includes above- and belowground biomass) in forest land remaining forest land; tonnes C yr^{-1}

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[1] Lands that have been converted to another land use should be tracked under the appropriate sections for as long as carbon dynamics are influenced by the conversion and follow up dynamics. 20 years is consistent with *IPCC Guidelin*es, but Tier 3 methods may use longer periods where appropriate to national circumstances.

$\Delta C_{FF_{DOM}}$ = annual change in carbon stocks in dead organic matter (includes dead wood and litter) in forest land remaining forest land; tonnes C yr^{-1}

$\Delta C_{FF_{Soils}}$ = annual change in carbon stocks in soils in forest land remaining forest land; tonnes C yr^{-1}

To convert tonnes C to Gg CO_2, multiply the value by 44/12 and 10^{-3}. For the convention (signs), refer to Section 3.1.7 or Annex 3A.2 (Reporting Tables and Worksheets).

3.2.1.1 CHANGE IN CARBON STOCKS IN LIVING BIOMASS

Carbon stock change is calculated by multiplying the difference in oven dry weight of biomass increments and losses with the appropriate carbon fraction. This section presents methods for estimating biomass increments and the losses. Increments include biomass growth. Losses include fellings, fuelwood gathering, and natural losses.

3.2.1.1.1 METHODOLOGICAL ISSUES

3.2.1.1.1.1 Choice of Method

Two methods are feasible for estimating carbon stock changes in biomass:

Method 1 (also called the **default method**) requires the biomass carbon loss to be subtracted from the biomass carbon increment for the reporting year (Equation 3.2.2).

EQUATION 3.2.2
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS
IN FOREST LAND REMAINING FOREST LAND (DEFAULT METHOD)

$$\Delta C_{FF_{LB}} = (\Delta C_{FF_G} - \Delta C_{FF_L})$$

Where:

$\Delta C_{FF_{LB}}$ = annual change in carbon stocks in living biomass (includes above- and belowground biomass) in forest land remaining forest land, tonnes C yr^{-1}

ΔC_{FF_G} = annual increase in carbon stocks due to biomass growth, tonnes C yr^{-1}

ΔC_{FF_L} = annual decrease in carbon stocks due to biomass loss, tonnes C yr^{-1}

Method 2 (also called the **stock change method**) requires biomass carbon stock inventories for a given forest area at two points in time. Biomass change is the difference between the biomass at time t_2 and time t_1, divided by the number of years between the inventories (Equation 3.2.3).

EQUATION 3.2.3
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

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

Where:

$\Delta C_{FF_{LB}}$ = annual change in carbon stocks in living biomass (includes above- and belowground biomass) in forest land remaining forest land, tonnes C yr^{-1}

C_{t_2} = total carbon in biomass calculated at time t_2, tonnes C

C_{t_1} = total carbon in biomass calculated at time t_1, tonnes C

V = merchantable volume, $m^3\ ha^{-1}$

D = basic wood density, tonnes d.m. m^{-3} merchantable volume

BEF_2 = biomass expansion factor for conversion of merchantable volume to aboveground tree biomass, dimensionless.

R = root-to-shoot ratio, dimensionless

CF = carbon fraction of dry matter (default = 0.5), tonnes C $(\text{tonne d.m.})^{-1}$

The default method is applicable for all tiers, while the data requirements for the stock change method exclude this option for the Tier 1 approach. In general the stock change method will provide good results for relatively large increases or decreases of biomass, or where very accurate forest inventories are carried out. However for forest areas of mixed stands, and/or where biomass change is very low compared to the total amount of biomass, there is a risk with the stock change method of the inventory error being larger than the expected change. In such conditions incremental data may give better results. The choice of using default or stock change method at the appropriate tier level will therefore be a matter for expert judgment, taking the national inventory systems and forest properties into account.

The default method for estimating the changes in aboveground and belowground biomass uses a series of equations. These require activity data on area of different land-use categories, according to different forest types or management systems, corresponding emission and removal factors, and factors to estimate biomass loss. The accuracy of the estimate depends on the tier chosen for biomass estimation, and the data available.

It is *good practice* to choose tier by following the decision tree as shown in Figure 3.1.1. This promotes efficient use of available resources, taking into account whether the biomass of this category is a key category as described in Chapter 5, Section 5.4. In general:

Tier 1: Tier 1 applies to countries in which either the subcategory (forest land remaining forest land or biomass carbon pool) is not a key category or little or no country-specific activity data and emission/removal factors exist nor can be obtained.

Tier 2: Tier 2 applies where forest land remaining forest land or biomass carbon is a key category. Tier 2 should be used in countries where country-specific estimates of activity data and emission/removal factors are available or can be gathered at expenses that weigh favourably against expenses required for other land-use categories.

Tier 3: Tier 3 applies where the forest land remaining forest land or biomass carbon is a key category. This requires use of detailed national forest inventory data supplemented by dynamic models or allometric equations calibrated to national circumstances that allow for direct calculation of biomass increment. Tier 3 approach for carbon stock change allows for a variety of methods, and implementation may differ from one country to another, due to differences in inventory methods and forest conditions. Proper documentation of the validity and completeness of the data, assumptions, equations and models used is therefore a critical issue at Tier 3.

EQUATIONS FOR ESTIMATING CHANGE IN CARBON STOCKS IN LIVING BIOMASS ($\Delta C_{FF_{LB}}$) USING THE DEFAULT METHOD

Annual Increase in Carbon Stocks due to Biomass Increment in Forest land Remaining Forest land (ΔC_{FF_G})

Estimation of annual increase in carbon stocks due to biomass increment in forest land remaining forest land requires estimates of area and annual increment of total biomass, for each forest type and climatic zone in the country (Equation 3.2.4). The carbon fraction of biomass has a default value of 0.5, although higher tier methods may allow for variation with different species, different components of a tree or a stand (stem, roots and leaves) and age of the stand.

EQUATION 3.2.4

ANNUAL INCREASE IN CARBON STOCKS DUE TO BIOMASS INCREMENT IN FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF_G} = \sum_{ij} (A_{ij} \bullet G_{TOTAL_{ij}}) \bullet CF$$

Where:

ΔC_{FF_G} = annual increase in carbon stocks due to biomass increment in forest land remaining forest land by forest type and climatic zone, tonnes C yr^{-1}

A_{ij} = area of forest land remaining forest land, by forest type ($i = 1$ to n) and climatic zone ($j = 1$ to m), ha

$G_{TOTAL_{ij}}$ = average annual increment rate in total biomass in units of dry matter, by forest type ($i = 1$ to n) and climatic zone ($j = 1$ to m), tonnes d.m. $\text{ha}^{-1}\ \text{yr}^{-1}$

CF = carbon fraction of dry matter (default = 0.5), tonnes C $(\text{tonne d.m.})^{-1}$

Average Annual Increment in Biomass (G_{TOTAL})

G_{TOTAL} is the expansion of annual increment rate of aboveground biomass (G_W) to include its belowground part, involving multiplication by the ratio of belowground biomass to aboveground biomass (often called the root-to-shoot ratio (R)) that applies to increments. This may be achieved directly where G_W data are available as in the case of naturally regenerated forests or broad categories of plantation. In case G_W data are not available, the increment in volume (I_V) can be used with biomass expansion factor for conversion of annual net increment to aboveground biomass increment. Equation 3.2.5 shows the relationship:

EQUATION 3.2.5

AVERAGE ANNUAL INCREMENT IN BIOMASS

$G_{TOTAL} = G_W \bullet (1 + R)$ **(A)** In case aboveground biomass increment (dry matter) data are used directly. Otherwise G_W is estimated using equation B or its equivalent

$G_W = I_V \bullet D \bullet BEF_1$ **(B)** In case net volume increment data are used to estimate G_W.

Where:

G_{TOTAL} = average annual biomass increment above and belowground, tonnes d.m. ha^{-1} yr^{-1}

G_W = average annual aboveground biomass increment, tonnes d.m. ha^{-1} yr^{-1}; Tables 3A.1.5 and 3A.1.6

R = root-to-shoot ratio appropriate to increments, dimensionless; Table 3A.1.8

I_V =average annual net increment in volume suitable for industrial processing, m^3 ha^{-1} yr^{-1}; Table 3A.1.7

D = basic wood density, tonnes d.m. m^{-3}; Table 3A.1.9

BEF_1 = biomass expansion factor for conversion of annual net increment (including bark) to aboveground tree biomass increment, dimensionless; Table 3A.1.10

Basic wood density (D) and biomass expansion factors (BEF) vary by forest type, age, growing conditions, stand density and climate (Kramer, 1982; Brown, 1997; Lowe *et al.*, 2000; Koehl, 2000). Table 3A.1.10 provides default values of BEF by forest type and climatic zone for use with the minimum diameter ranges indicated. The BEFs serve as substitute for the expansion ratios in the *IPCC Guidelines* which are used to calculate non-merchantable biomass (limbs, small trees etc.) that are cut during felling and left to decay.

For countries using Tier 2 methods, it is *good practice* to use country-specific as well as species-specific basic wood density and BEF values, if available nationally.

D as well as BEF values should be estimated at the species level in countries adopting Tier 3. BEFs for biomass increment, growing stock and harvest differ for a given species or a stand. For Tiers 2 and 3, inventory experts are encouraged to develop country-specific D and BEF values for growing stock, biomass increment and harvests separately. If country-specific factors and approaches are used, they should be appropriately verified and documented in accordance with the general requirements set out in Chapter 5.

Due to country-specific conditions (e.g. Lehtonen *et al.*, 2003; Smith *et al.*, 2003) BEF and D may be combined in one value. In such cases, the guidance given on BEF and D should be applied to the combined values as appropriate.

Annual Decrease in Carbon Stocks Due to Biomass Loss in Forest land Remaining Forest land (ΔC_{FF_L})

Annual biomass loss is a sum of losses from commercial roundwood fellings, fuelwood gathering, and other losses (Equation 3.2.6):

EQUATION 3.2.6

ANNUAL DECREASE IN CARBON STOCKS DUE TO BIOMASS LOSS IN FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF_L} = L_{fellings} + L_{fuelwood} + L_{other\ losses}$$

Where:

ΔC_{FF_L} = annual decrease in carbon stocks due to biomass loss in forest land remaining forest land, tonnes C yr^{-1}

$L_{fellings}$ = annual carbon loss due to commercial fellings, tonnes C yr^{-1} (See Equation 3.2.7)

$L_{fuelwood}$ = annual carbon loss due to fuelwood gathering, tonnes C yr^{-1} (See Equation 3.2.8)

$L_{other\ losses}$ = annual other losses of carbon, tonnes C yr^{-1} (See Equation 3.2.9)

The equation for estimating the annual carbon loss due to commercial fellings is provided in Equation 3.2.7:

EQUATION 3.2.7
ANNUAL CARBON LOSS DUE TO COMMERCIAL FELLINGS

$$L_{fellings} = H \bullet D \bullet BEF_2 \bullet (1 - f_{BL}) \bullet CF$$

Where:

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

H = annually extracted volume, roundwood, m^3 yr^{-1}

D = basic wood density, tonnes d.m. m^{-3}; Table 3A.1.9

BEF_2 = biomass expansion factor for converting volumes of extracted roundwood to total aboveground biomass (including bark), dimensionless; Table 3A.1.10

f_{BL} = fraction of biomass left to decay in forest (transferred to dead organic matter)

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

In applying this equation there are two choices:

(i) Total biomass associated with the volume of the extracted roundwood is considered as an immediate emission. This is the default assumption and implies that f_{BL} should be set to 0. This assumption should be made unless changes in dead organic matter are being explicitly accounted for, which implies use of higher tiers under Section 3.2.1.2 below.

(ii) A proportion of the biomass is transferred to the dead wood stock. In this case, f_{BL} should be obtained by expert judgment or based on empirical data (Tier 2 or 3). Annex 3.A.11 provides default data on f_{BL} for use at Tier 2.

The carbon loss due to fuelwood gathering is estimated using Equation 3.2.8:

EQUATION 3.2.8
ANNUAL CARBON LOSS DUE TO FUELWOOD GATHERING

$$L_{fuelwood} = FG \bullet D \bullet BEF_2 \bullet CF$$

Where:

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

FG = annual volume of fuelwood gathering, m^3 yr^{-1}

D = basic wood density, tonnes d.m. m^{-3}; Table 3A.1.9

BEF_2 = biomass expansion factor for converting volumes of extracted roundwood to total aboveground biomass (including bark), dimensionless; Table 3A.1.10

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

Other carbon losses in managed forest land include losses from disturbances such as windstorms, pest outbreaks, or fires. A generic approach for estimating the amount of carbon lost from such disturbances is provided below. In the specific case of losses from fire on managed forest land, including wildfires and controlled fires, this method should be used to provide input to the methodology in Section 3.2.1.4 (Non-CO_2 Greenhouse Gas Emissions) to estimate CO_2 and non-CO_2 emissions from fires.

It is *good practice* to report all areas affected by disturbances such as fires, pest outbreaks and windstorms that occur in managed forest lands irrespective of whether these were the result of human activity. Natural disturbances occurring on unmanaged forest, and not resulting in land-use change, should not be included. Losses in biomass accounted as commercial harvest or fuelwood should not be included under the losses due to other disturbances.

The impact of disturbances on forest ecosystem varies with the type and severity of disturbance, the conditions under which they occur (e.g. weather) and the ecosystem characteristics. The proposed generic method illustrated in Equation 3.2.9 assumes complete destruction of forest biomass in the event of a disturbance – hence the default methodology addresses "stand-replacing" disturbances only. Countries reporting under Tier 3 should consider both stand-replacing and non-stand replacing disturbances.

EQUATION 3.2.9

ANNUAL OTHER LOSSES OF CARBON

$$L_{\text{other losses}} = A_{\text{disturbance}} \bullet B_W \bullet (1 - f_{BL}) \bullet CF$$

Where:

$L_{\text{other losses}}$ = annual other losses of carbon, tonnes C yr^{-1}

$A_{\text{disturbance}}$ = forest areas affected by disturbances, ha yr^{-1}

B_W = average biomass stock of forest areas, tonnes d.m. ha^{-1}; Tables 3A.1.2, 3A.1.3, and 3A.1.4

f_{BL} = fraction of biomass left to decay in forest (transferred to dead organic matter); Table 3A.1.11

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

Tier 1: Under Tier 1, disturbances are assumed to affect the aboveground biomass only; it is also assumed that all aboveground biomass carbon is lost upon disturbance. Hence, f_{BL} is equal to zero.

Tier 2: Countries reporting at higher tiers, which account for emissions/removals from all forest pools, have to distinguish between the proportion of the pre-disturbance biomass that is destroyed and causes emissions of greenhouse gas, and that which is transferred into the dead organic matter pools and later decay.

Tier 3: Countries reporting under Tier 3 should consider all significant disturbances, both stand-replacing and non-stand replacing. When accounting for the impact of non-stand-replacing disturbances, countries may add a term to Equation 3.2.9 to adjust for the proportion of pre-disturbance biomass which is not affected by the disturbance.

SUMMARY OF STEPS FOR ESTIMATING CHANGE IN CARBON STOCKS IN LIVING BIOMASS ($\Delta C_{FF_{LB}}$) USING THE DEFAULT METHOD

Step 1: Using guidance from Chapter 2 (approaches in representing land areas), categorise the area (A) of forest land remaining forest land into forest types of different climatic zones, as adopted by the country. As a point of reference, Table 3A.1.1 provides national level data of forest area and annual change in forest area by region and by country as a means of verification;

Step 2: Estimate the average annual increment in biomass (G_{TOTAL}) using Equation 3.2.5. If data of the average annual aboveground biomass increment (G_W) are available, use Equation 3.2.5A. If not available, estimate G_W using Equation 3.2.5B;

Step 3: Estimate the annual increase in carbon stocks due to biomass increment (ΔC_{FF_G}) using Equation 3.2.4;

Step 4: Estimate the annual carbon loss due to commercial fellings ($L_{W \text{ fellings}}$) using Equation 3.2.7;

Step 5: Estimate annual carbon loss due to fuelwood gathering ($L_{W \text{ fuelwood}}$) using Equation 3.2.8;

Step 6: Estimate annual carbon loss due to other losses ($L_{\text{other losses}}$) using Equation 3.2.9;

Step 7: From the estimated losses in Steps 4 to 6, estimate the annual decrease in carbon stocks due to biomass loss (ΔC_{FF_L}) using Equation 3.2.6;

Step 8: Estimate the annual change in carbon stocks in living biomass ($\Delta C_{FF_{LB}}$) using Equation 3.2.2.

3.2.1.1.1.2 Choice of Emission/Removal Factors

Method 1 requires the annual biomass increment, according to each forest type and climatic zone in the country, plus emission factors related to biomass loss including losses due to fellings, fuelwood gathering and natural losses.

ANNUAL INCREASE IN BIOMASS

Annual Aboveground Biomass Increment, G_W

Tier 1: Tier 1 uses default values of the average annual increment in aboveground biomass (G_W) which are provided in Tables 3A.1.5 and 3A.1.6.

Tier 2: Tier 2 method uses country-specific data to calculate the gross mean annual biomass increment G_W. The country-specific data is often linked to merchantable volumes (I_V). Data on biomass expansion factor (BEF_1) and basic wood density (D) are needed to convert the available data to G_W. Table 3A.1.7 provides the default values for I_V and Tables 3A.1.10 and 3A.1.9 provide default values for BEF_1 and D, respectively.

Tier 3: Under Tier 3, a detailed forest inventory or monitoring system will be available which contains at least data on growing stock, and, ideally, also on annual increment. If appropriate allometric biomass functions are available it is *good practice* to use those equations directly. Carbon fraction and basic wood density could also be incorporated in such functions.

The detailed forest inventory should be used to provide initial conditions of forest carbon stocks in the forest inventory year. When the year of inventory does not correspond with the commitment period, mean annual increment or increment estimated by models (i.e. model capable of simulating forest dynamics), should be used.

Periodic forest inventories may be combined with annual planting and felling data to provide non-linear interpolations of increment between inventory years.

Belowground Biomass Increment

Tier 1: Belowground biomass increment, as a default assumption consistent with the *IPCC Guidelines* can be zero. Alternatively, default values for root-to-shoot ratios (R), which could be used to estimate belowground biomass, are provided Table 3A.1.8.

Tier 2: Country-specific root-to-shoot ratios should be used to estimate belowground biomass.

Tier 3: Nationally or regionally determined root-to-shoot ratios or increment models should be used. Preferably, belowground biomass should be incorporated in models for calculating total biomass increment.

ANNUAL BIOMASS LOSS

The *IPCC Guidelines* refer to biomass extraction (i.e. commercial fellings, removals for fuelwood and other wood use, and natural losses) as total biomass consumption from stocks leading to carbon release. Equation 3.2.6 sets out the three components more precisely.

In addition to commercial fellings of industrial wood and saw logs, fuelwood are mentioned more specifically, there may also be other types of non-commercial fellings, as wood cut for own consumption. This quantity may not be included in official statistics and may need to be estimated by survey.

Fellings

When computing carbon loss due to commercial fellings, the following emission/removal factors are needed: extracted volume of roundwood (H), basic wood density (D), and the fraction of biomass left to decay in forest (f_{BL}).

Where it is separable, fellings data should not be counted from forest land being converted to another land use since this would lead to double counting. The statistics on fellings are not likely to provide such separation on what lands the fellings are coming from, hence an amount of biomass similar to the biomass loss from lands converted from forest should be subtracted from the total fellings.

Extraction of roundwood is published in the UNECE/FAO Timber Bulletin and by FAO Yearbook of Forest Products. The latter is based primarily on data provided by the countries. In the absence of official data, FAO provides an estimate based on the best information available. Usually, the yearbook appears with a two-year time lag.

Tier 1: FAO data can be used as a Tier 1 default for H in Equation 3.2.7. The roundwood data includes all wood removed from forests which are reported in cubic meters underbark. The underbark data needs converting to overbark for use with BEF_2. For most tree species bark makes up about 10% to 20% of the overbark stem volume. Unless country-specific data are available, 15% should be used as a default value and the FAO overbark volume can be estimated by dividing the underbark estimate by 0.85 before using the values in Equation 3.2.7. It is *good practice* to verify, supplement, update and check the quality of data based on any additional data from national or regional surveys.

Tier 2: Country-specific data should be used.

Tier 3: Country-specific removals data from different forest categories should be used at the resolution corresponding to the Tier 3 forest model. If known, country-specific information on the dynamics of dead wood decay should be used to describe the time evolution of non-harvested biomass.

Fuelwood gathering

Estimation of carbon losses due to fuelwood gathering requires data on annual volume of fuelwood gathered (FG), basic wood density (D), and biomass expansion (BEF_2) for converting volumes of collected roundwood to total aboveground biomass.

The way fuelwood extraction takes place in different countries varies from ordinary fellings to the gathering of dead wood (the latter often as a fraction of 'f_{BL}' of Equation 3.2.7.). This calls for different approaches when calculating FG, as felling of trees for fuelwood use should be treated as carbon loss due to fellings .The equation for fuelwood gathering, in comparison with the equation for commercial fellings, does not have a variable for 'fraction left to decay', as it is assumed that a larger proportion of the trees is likely to be removed from forest. On the other hand, fuelwood gathering from the forest floor should not be expanded, as it represents a reduction of the dead wood stock equal to the amount extracted. At the lower tiers it is assumed that this does not affect the stock in dead wood (see Sec. 3.2.1.2).

This section deals only with fuelwood gathering in forest land remaining forest land. In the sections 'land converted to cropland, grassland, etc', explanation is given on how fuelwood used off-site, from the land use conversion, should be treated and compensated for in the fuelwood statistics.

Tier 1: FAO provides statistics on fuelwood and charcoal consumption data for all countries. Thus, under Tier 1, FAO statistics can be used directly but should be checked for completeness because in some cases FAO data may refer to specific activities taking place in particular forests rather than total fuelwood. If more complete information is available nationally, it should be used. It is *good practice* to locate the national source of data for the FAO such as the Ministry of Forests or Agriculture or any statistical organization. It is also *good practice* to separate fuelwood gathering from forest land remaining forest land and that coming from forest land conversion to other uses.

Tier 2: Country-specific data should be used, if available. It is *good practice* to verify and supplement the FAO data from many national surveys and studies. Further, it is *good practice* to conduct a few regional surveys of fuelwood consumption to validate the national or FAO data source. The national level, aggregate fuelwood consumption could be estimated by conducting regional level surveys of rural and urban households at different income levels, industries and establishments.

Tier 3: Fuelwood fellings data from national level studies should be used at the resolution required for the Tier 3 model, including the non-commercial fellings.

Traditional fuelwood gathering as well as commercial fuelwood felling from forest land remaining forest land sources should be generated at regional or disaggregated level through surveys. Fuelwood consumption depends on household incomes. Thus, it may be possible to develop models to estimate fuelwood consumption. The source of fuelwood should be clearly investigated to ensure no double counting occurs, between fuelwood from forest land remaining forest land and forest land converted to other uses.

A country adopting Tier 3 should undertake a systematic approach to estimate fuelwood consumption along with sources, through survey of households, industries and establishments. The survey could be conducted in different homogeneous climatic and socio-economic zones by adopting a statistical procedure (see Chapter 5, Section 5.3 on Sampling). Fuelwood consumption is likely to be different in rural and urban areas and during different seasons of a year. Thus, the study should be conducted separately in rural and urban areas and in different seasons. Fuelwood consumption models could be developed using income, level of urbanization, etc.

If fuelwood consumption data is in the form of commercial wood, reflecting only the merchantable wood, it needs to be converted to whole stand biomass.

Other losses

The estimate of other losses of carbon requires data on areas affected by disturbances ($A_{disturbance}$), the average biomass stocks of forest areas (B_W), and the fraction of biomass left to decay in forest (f_{BL}).

It is *good practice* to report all areas affected by disturbances such as fires, pest and disease outbreaks and windstorms that occur in managed forest lands irrespective of whether these were the result of human activity. However, natural disturbances occurring on unmanaged forest, and not resulting in land-use change, should not be included. Depending on their intensity, fires, windstorms and pests outbreaks affect a variable proportion of trees in a stand. It is *good practice* to categorise the affected area, as far as possible, according to the nature and intensity of disturbances. Losses in biomass accounted as commercial harvest or fuelwood should not be included under the losses due to other disturbances.

Tier 1: Tier 1 approach is to obtain area of disturbance for the actual year. There are some international data available on disturbances (see below) but in general default information is limited, and national assessment, making use of data available at the local level following the disturbance, will be necessary to establish the area affected. It may also be possible to use aerial survey data.

In the case of fire, both CO_2 and non-CO_2 emissions occur from combusted fuels (standing biomass including understorey, slash, dead wood and litter). Fire may consume a high proportion of under storey vegetation. See Section 3.2.1.4 for methodology to estimate non-CO_2 emissions from fire and Equation 3.2.9 for calculating CO_2 emissions from fire.

Annex 3A.1 provides several tables to be used in connection with Equation 3.2.9.

- Table 3A.1.12 provides default values of combustion factor to be used as $(1 - f_{BL})$ in case the country has good growing stock biomass data; in this case the share lost is used;
- Table 3A.1.13 provides default values of biomass consumption to be used as $[B_W \bullet (1 - f_{BL})]$ in case the growing stock biomass data are not so good; and
- Table 3A.1.14 provides default values of combustion efficiency in cases where fire is used as a means for land-use change.

Tier 2: Under Tier 2, biomass growing stock changes due to major disturbances will be taken into account by forest category, type of disturbance and intensity. Average values for biomass stocks are obtained from national data.

Tier 3: Estimation of growth rate using two inventories and the loss of biomass from disturbances that have happened between the inventories are included. If the year of the disturbance is unknown, the result will be a reduction of the average growth rate for the period. If disturbances occur after the last inventory, losses will have to be calculated similar to Tier 2 approach.

A database on rate and impact of natural disturbances by type, for all European countries (Schelhaas *et al.*, 2001), can be found at: http://www.efi.fi/projects/dfde

A UNEP database on global burnt area can be found at:
http://www.grid.unep.ch/activities/earlywarning/preview/ims/gba/

However, one should note that the UNEP database is only valid for year 2000. In many countries interannual variability in burned area is large, so these figures will not provide a representative average.

3.2.1.1.1.3 Choice of Activity Data

AREA OF MANAGED FOREST LAND

All tiers require information on areas of managed forest land.

Tier 1: Tier 1 uses data of forest area which can be obtained through national statistics, from forest services (which may have information on areas of different management practices), conservation agencies (especially for areas managed for natural regeneration), municipalities, survey and mapping agencies. Cross-checks should be made to ensure complete and consistent representation for avoiding omissions or double counting as specified in Chapter 2. If no country data are available, aggregate information can be obtained from international data sources (FAO, 1995; FAO 2001, TBFRA, 2000). It is *good practice* to verify, validate, and update the FAO data using national sources.

Tier 2: Tier 2 uses country-defined national data sets with a resolution sufficient to ensure appropriate representation of land areas in line with provisions of Chapter 2 of this report.

Tier 3: Tier 3 uses national data on managed forest lands from different sources, notably national forest inventories, registers of land-use and land-use changes, or remote sensing. These data should give a full accounting of all land use transitions to forest land and disaggregate along climate, soil and vegetation types.

3.2.1.1.1.4 Uncertainty Assessment

This section considers source-specific uncertainties relevant to inventory estimates made for forest land remaining forest. Estimating country-specific and/or disaggregated values entails getting more accurate information on uncertainties than given below. Section 5.3 on Sampling, in Chapter 5, provides information on uncertainties associated with sample-based studies.

EMISSION AND REMOVAL FACTORS

The uncertainty of basic wood density of pine, spruce and birch trees (predominantly stems) is under 20% in studies of Hakkila (1968, 1979) in Finland. The variability between forest stands should be lower or at most the same as for trees. It is concluded that overall uncertainty of country-specific basic wood density values should be about 30%.

Lehtonen *et al.* (2003) analyzed stand level biomass expansion factors for pine, spruce and birch dominated forests in Finland. The uncertainty of estimates was about 10%. The study was made for predominantly managed forests, thus, it underestimates about 2 times the variation between forests in the boreal zone. Based on the above, as estimated by expert judgment, overall uncertainty of BEFs should be 30%. The uncertainty of root-to-shoot ratio is likely to have similar value of an order of 30%.

The major source of uncertainty of estimates, in using default wood density and BEFs, is related to applicability of these parameters for diverse age and composition structure of specific stands. To reduce the uncertainty associated with this issue, the countries are encouraged to develop country-specific BEFs or share regional experience on values derived for forest stands that fit most in their conditions. In case the country-specific or regional-specific values are unavailable, the sources of default emission and removal factors should be checked and their correspondence with specific conditions of a country should be examined. The efforts should be made to apply the default values that have the highest correspondence with stand structure, climate and growth conditions of a particular country.

Vuokila and Väliaho (1980) report values of increment for artificially regenerated pine and spruce stands in Finland that vary by 50% around the average. The causes of variation include climate, site growth conditions, and soil fertility. Because artificially regenerated and managed stands are less variable than natural boreal forests, the overall variability of default values for increment for this climatic zone is expected to be a factor of two. Based on higher biological diversity of temperate and tropical forests, one can expect that their default increment values may vary by a factor of three. The major ways to improve accuracy of estimates are associated with application of country-specific or regional increment stratified by forest type. If the default values of increment are used, the uncertainty of estimates should be clearly indicated and documented.

The data on commercial fellings are relatively accurate. Therefore, their uncertainty is less than 30%. However, the data on total fellings may be incomplete, due to illegal fellings and (or) underreporting due to tax regulations. Wood that are used directly, without being sold or processed by others than the person taking the wood from forest are not likely to be included in any statistics. However, it must be noted that illegal fellings and underreporting in most cases constitute minor part of carbon stock withdrawals from forests and hence, they should not affect overall estimates and associated uncertainties so much. The amount of wood removed from forests after storm breaks and pest outbreaks varies a lot both in time and volumes. No default data can be provided on this type of losses. The uncertainties associated with these losses could be estimated by expert judgment based on amount of damaged wood directly withdrawn from forest (if available) or based on the data on the damaged wood subsequently used for commercial and other purposes.

If fuelwood gathering is treated separately from fellings, the relevant uncertainties might be high. International data sources provide uncertainty estimates that could be used together with appropriate data on fuelwood. The uncertainties for national data on fuelwood gathering could be obtained from local forestry service or statistical agency or can be estimated with the use of expert judgment.

ACTIVITY DATA

Area data should be obtained using the methods in Chapter 2. Uncertainties vary between 1-15% in 16 European countries (Laitat *et al.*, 2000). The uncertainty of remote sensing methods is ±10-15%. Sub-units will have greater uncertainty unless the number of samples is increased – other things being equal for uniform sampling an area one tenth of the national total will have one tenth the number of sample points and hence the uncertainty will be larger by about the square root of 10, or roughly 3.16. In case the national data on areas of forest lands are not available, the inventory preparers should refer to international data sources and use uncertainty provided by them.

3.2.1.2 CHANGE IN CARBON STOCKS IN DEAD ORGANIC MATTER

This section elaborates *good practices* for estimating carbon stock changes associated with dead organic matter pools. The *IPCC Guidelines* assume as a default that changes in carbon stocks in these pools are not significant and can be assumed zero, i.e. that inputs balance losses so that net dead organic matter carbon stock changes are zero. However, the *IPCC Guidelines* say that dead organic matter should be considered in future work on inventory methods because the quantity of carbon in dead organic matter is a significant reservoir in many of the world's forests. Note that the dead organic matter pools only need to be estimated if Tier 2 or Tier 3 is chosen.

Separate guidance is provided here for two types of dead organic matter pools: 1) dead wood and 2) litter. Table 3.1.2 in Section 3.1.3 of this report provides detailed definitions of these pools. Equation 3.2.10 summarises the calculation for change in dead organic matter carbon pools.

EQUATION 3.2.10

ANNUAL CHANGE IN CARBON STOCKS IN DEAD ORGANIC MATTER IN FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF_{DOM}} = \Delta C_{FF_{DW}} + \Delta C_{FF\ LT}$$

Where:

$\Delta C_{FF_{DOM}}$ = annual change in carbon stocks in dead organic matter (includes dead wood and litter) in forest land remaining forest land, tonnes C yr^{-1}

$\Delta C_{FF_{DW}}$ = change in carbon stocks in dead wood in forest land remaining forest land, tonnes C yr^{-1}

$\Delta C_{FF_{LT}}$ = change in carbon stocks in litter in forest land remaining forest land, tonnes C yr^{-1}

3.2.1.2.1 METHODOLOGICAL ISSUES

DEAD WOOD

Dead wood is a diverse pool with many practical problems for measuring in the field and associated uncertainties about rates of transfer to litter, soil, or emissions to the atmosphere. Carbon in dead wood is highly variable between stands across the landscape, both in managed stands (Duvall and Grigal, 1999; Chojnacky and Heath, 2002) and even in unmanaged stands (Spies *et al.*, 1988). Amounts of dead wood depend on the time of last disturbance, the amount of input (mortality) at the time of the disturbance (Spies *et al.* 1988), natural mortality rates, decay rate, and management. The proposed approach recognizes the regional importance of forest type, disturbance regime, and management regime on the carbon stocks in dead wood, and allows for the incorporation of available scientific knowledge and data.

LITTER

The accumulation of litter is a function of the annual amount of litterfall, which includes all leaves, twigs and small branches, fruits, flowers, and bark, minus the annual rate of decomposition. The litter mass is also influenced by the time of last disturbance, and the type of disturbance. During the early stages of stand development, litter increases rapidly. Management such as timber harvesting, slash burning, and site preparation dramatically alter litter properties (Fisher and Binkley, 2000), but there are few studies clearly documenting the effects of management on litter carbon (Smith and Heath, 2002).

The proposed approach recognizes the important impact of forest type, and disturbance regimes or management activities on the carbon in litter, and allows for the incorporation of the available scientific knowledge and data. The methodology assumes:

- Carbon in the litter pool eventually attains a spatially-averaged, stable value specific to the forest type, disturbance regime, and management practice;
- Changes leading to a new stable litter carbon value occur over a transition time. A column in Table 3.2.1 features updated default factors for the transition period. The value of carbon in litter generally stabilizes sooner than aboveground biomass stocks; and
- Carbon sequestration during the transition to a new equilibrium is linear.

3.2.1.2.1.1 Choice of Method

Depending on available data, the country may arrive at a different tier for the dead wood and litter pools.

Calculation procedure for change in carbon stocks in dead wood

The *IPCC Guidelines* do not require estimation or reporting on dead wood or litter, on the assumption that the time average value of these pools will remain constant with inputs to dead matter pools balanced by outputs. The GPG retains this default assumption but provides advice for reporting at higher tiers for Convention purposes and to meet the requirements set out in Chapter 4.

The change in carbon stocks in dead wood for an area of forest land can be calculated using two options, given in Equation 3.2.11 and Equation 3.2.12. The forest land areas should be categorised by forest type, disturbance regime, management regime, or other factors significantly affecting dead wood carbon pools. Gross CO_2 emissions from dead wood should be calculated as part of Equation 3.2.11 at Tier 2 or Tier 3.

EQUATION 3.2.11
ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD IN FOREST LAND REMAINING FOREST LAND (OPTION 1)

$$\Delta C_{FF_{DW}} = [A \bullet (B_{into} - B_{out})] \bullet CF$$

Where:

$\Delta C_{FF_{DW}}$ = annual change in carbon stocks in dead wood in forest land remaining forest land, tonnes C yr^{-1}

A = area of managed forest land remaining forest land, ha

B_{into} = average annual transfer into dead wood, tonnes d.m. ha^{-1} yr^{-1}

B_{out} = average annual transfer out of dead wood, tonnes d.m. ha^{-1} yr^{-1}

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

B_{into}, the annual transfer into the dead wood pool, includes biomass cut for harvest but left on the site, natural mortality, and biomass from trees killed by fire or other disturbances, but not emitted at the time of disturbance. B_{out}, average annual transfer out of dead wood pool, is the carbon emissions from the dead wood pool. These are calculated by multiplying the dead wood carbon stock by a decay rate. The *IPCC Guidelines*, assume that B_{into} and B_{out} balance so that $\Delta C_{FF_{DW}}$ equals zero.

The equation chosen depends on available data. Transfers into and out of a dead wood pool for Equation 3.2.11 may be difficult to measure. The stock change method described in Equation 3.2.12 is used with survey data sampled according to the principles set out in Section 5.3.

EQUATION 3.2.12

ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD IN FOREST LAND REMAINING FOREST LAND (OPTION 2)

$$\Delta C_{FF_{DW}} = [A \bullet (B_{t_2} - B_{t_1}) / T] \bullet CF$$

Where:

$\Delta C_{FF_{DW}}$ = annual change in carbon stocks in dead wood in forest land remaining forest land, tonnes C yr^{-1}

A = area of managed forest land remaining forest land, ha

B_{t1} = dead wood stock at time t_1 for managed forest land remaining forest land, tonnes d.m. ha^{-1}

B_{t2} = dead wood stock at time t_2 (the previous time) for managed forest land remaining forest land, tonnes d.m. ha^{-1}

T (= $t_2 - t_1$) = time period between time of the second stock estimate and the first stock estimate, yr

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

The decision tree in Figure 3.1.1 (Section 3.1.6) provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures. Theoretically, Equations 3.2.11 and 3.2.12 should give the same carbon estimates. In practice, data availability and desired accuracy determine choice of equation.

Tier 1 (Default): The *IPCC Guidelines*, consistent with reporting under Tier 1, assume that the average transfer rate into the dead wood pool is equal to the transfer rate out of the dead wood pool so the net change is zero. This assumption means that magnitude of the dead wood carbon pool need not be quantified. Countries experiencing significant changes in forest types, or disturbance or management regimes in their forests are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

Tier 2: Equation 3.2.11 or Equation 3.2.12 is used, depending on the type of data available nationally. Activity data are defined by the country by significant forest types, disturbance and management regimes, or other important variables affecting dead wood pool. Where Equation 3.2.11 is used, transfer rates are determined for the country or taken from matching regional sources such as data from nearby countries. Country-specific decay rates are used to estimate carbon emissions from dead wood stocks. When country-specific dead wood carbon stocks defaults are known, Equation 3.2.12 is used.

Tier 3: Tier 3 methods are used where countries have country-specific emission factors, and substantial national methodology. Country-defined methodology may be based on detailed inventories of permanent sample plots for their managed forests, and/or models. The statistical design of the inventory, consistent with the principles set out in Chapter 5, will provide information on the uncertainties associated with the inventory. Models used will follow the principles set out in Chapter 5. Equation 3.2.11 or Equation 3.2.12 is used, depending on the available data and methodology.

LITTER

Calculation procedure for change in carbon stocks in litter

The conceptual approach to estimating changes in carbon stocks in litter is to calculate the net annual changes in litter stocks for an area of forest land undergoing a transition from state *i* to state *j* as in Equation 3.2.13:

EQUATION 3.2.13
ANNUAL CHANGE IN CARBON STOCKS IN LITTER IN FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF_{LT}} = \Sigma_{i,j} [(C_j - C_i) \bullet A_{ij}] / T_{ij}$$

where,

$$C_i = LT_{ref(i)} \bullet f_{man\ intensity(i)} \bullet f_{dist\ regime(i)}$$

Where:

$\Delta C_{FF_{LT}}$ = annual change in carbon stocks in litter, tonnes C yr^{-1}

C_i = stable litter stock, under previous state *i*, tonnes C ha^{-1}

C_j = stable litter stock, under current state *j*, tonnes C ha^{-1}

A_{ij} = forest area undergoing a transition from state *i* to *j*, ha

T_{ij} = time period of the transition from state *i* to state *j*, yr. The default is 20 years

$LT_{ref(i)}$ = the reference stock of litter under native, unmanaged forest, corresponding to state *i*, tonnes C ha^{-1}

$f_{man\ intensity(i)}$ = adjustment factor reflecting the effect of management intensity or practices on LT_{ref} in state *i*, dimensionless

$f_{dist\ regime(i)}$= adjustment factor reflecting a change in the disturbance regime with respect to LT_{ref} in state *i*, dimensionless

The values of the default adjustment factors reflecting the effect of management intensity or disturbance regime are 1.0. Sometimes data on litter pools are collected in terms of dry matter, not carbon. To convert to dry matter mass of litter to carbon, multiply the mass by a default value of 0.370 (Smith and Heath, 2002), not the carbon fraction used for biomass.

The transition from C_i to C_j is assumed to take place over a transition period of T years (default = 20 years). The total litter carbon pool changes in any year equals the sum of the annual emissions/removals for all forest lands having undergone changes in forest types, management practices or disturbance regimes for a period of time shorter than T years. Updated default values are presented in Table 3.2.1 for litter carbon stocks for mature forest land remaining forest, net accumulation rates for the 20 year default, updated default transition period lengths, and net accumulation rates for the updated default transition period lengths.

The decision tree in Figure 3.1.1 (Section 3.1.6) provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures.

Tier 1 (Default): The *IPCC Guidelines,* consistent with reporting under Tier 1, assume that the average transfer rate into the litter pool is equal to the transfer rate out of the litter pool so the net change is zero. This assumption means that magnitude of the litter pool need not be quantified. Countries experiencing significant changes in forest types or disturbance or management regimes in their forests are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

Tier 2: Equation 3.2.13 or a formulation of Equation 3.2.11 for litter carbon is used, depending on the type of data available nationally. Activity data are defined by the country by significant forest types, disturbance and management regimes, or other important variables affecting dead wood pool. Where transfer rates are determined for the country or taken from matching regional sources such as data from nearby countries, Equation 3.2.11 formulated for litter is used. Country-specific decay rates are used to estimate carbon emissions from dead wood stocks. Where litter carbon pools are measured consistently over time, Equation 3.2.12 is used.

Tier 3: Methodology for estimating litter carbon changes involves the development, validation, and implementation of a domestic inventory scheme or inventory systems combined with the use of models. This tier features pools that are more closely linked, perhaps by taking measurements or samples of all forest pools at the same location. Given the spatial and temporal variability and uncertainty in litter carbon, countries in which litter C changes from managed forests are a key category, are encouraged to quantify changes using statistically-designed inventories or advanced models proven to be capable of accurately predicting site-specific changes. The statistical design of the inventory, consistent with the principles set out in Chapter 5, will provide information on the uncertainties associated with the inventory. Models used will follow the principles set out in Chapter 5. Depending on the available data and methodology, Equation 3.2.13 or a litter variant of Equation 3.2.11 is used.

TABLE 3.2.1
UPDATED DEFAULTS FOR LITTER CARBON STOCKS (TONNES C HA^{-1}) AND TRANSITION PERIOD (YEARS)
(Net annual accumulation of litter carbon is based mostly on data for managed forest and default period of 20 years)

Climate	Forest Type							
	Broadleaf Deciduous	**Needleleaf Evergreen**	**Broadleaf Deciduous**	**Needleleaf Evergreen**	**Broadleaf Deciduous**	**Needleleaf Evergreen**	**Broadleaf Deciduous**	**Needleleaf Evergreen**
	Litter carbon stock of mature forests (tonnes C ha^{-1})		Length of transition period (years)		Net annual accumulation of litter C over length of transition period [bc] (tonnes C ha^{-1} yr^{-1})		Net annual accumulation of litter C, based on 20 year default (tonnes C ha^{-1} yr^{-1})	
Boreal, dry	25 (10-58)	31 (6-86)	50	80	0.5	0.4	1.2	1.6
Boreal, moist	39 (11-117)	55 (7-123)	50	80	0.8	0.7	2.0	2.8
Cold Temperate, dry	28 (23-33)[a]	27 (17-42) [a]	50	80	0.6	0.4	1.4	1.4
Cold temperate, moist	16 (5-31) [a]	26 (10-48) [a]	50	50	0.3	0.5	0.8	1.3
Warm Temperate, dry	28.2 (23.4-33.0)[a]	20.3 (17.3-21.1)[a]	75	75	0.4	0.3	1.4	1.0
Warm temperate, moist	13 (2-31) [a]	22 (6-42)[a]	50	30	0.3	0.7	0.6	1.1
Subtropical	2.8 (2-3)	4.1	20	20	0.1	0.2	0.1	0.2
Tropical	2.1 (1-3)	5.2	20	20	0.1	0.3	0.1	0.3

Source: Siltanen *et al.*, 1997; and Smith and Heath, 2002; Tremblay *et al.*, 2002; and Vogt *et al.*,1996, converted from mass to carbon by multiplying by conversion factor of 0.37 (Smith and Heath, 2002).

Note: Ages follow Smith and Heath (2002).

[a] Values in parentheses marked by superscript "a" are the 5th and 95th percentiles from simulations of inventory plots, while those without superscript "a" indicate the entire range.

[b] These columns indicates the annual increase in litter carbon when starting from bare ground in land converted forest land.

[c] Note that the accumulation rates are for carbon being absorbed from the atmosphere. However, depending on the methodology, these may be transfers from other pools.

3.2.1.2.1.2 Choice of Emission/Removal Factors

DEAD WOOD

Tier 1: By default, it is assumed that the dead wood carbon stocks in all managed forests remaining forests are stable.

Tier 2: Country-specific values for transfer of carbon in live trees that are harvested to harvest residues can be derived from domestic expansion factors, taking into account the forest type (coniferous/broadleaved/ mixed), the rate of biomass utilization, harvesting practices and the amount of damaged trees during harvesting operations. Country-specific values for disturbance regimes could be derived from scientific studies. If country-specific input factors are derived, corresponding loss factors for harvest and disturbance regimes should also be derived from country-specific data.

Tier 3: For Tier 3, countries should develop their own methodologies and parameters for estimating changes in dead wood. Such approaches should be undertaken as part of the national forest inventory, with periodic sampling according to the principles set our in Section 5.3, which can be coupled with modeling studies to capture the dynamics of all forest-related pools. Tier 3 methods provide estimates of greater certainty than lower tiers and feature a greater link between individual forest pools. Some countries have developed disturbance matrices that provide, for each type of disturbance, a carbon reallocation pattern among different pools (Kurz and Apps, 1992). Other important parameters in a modeled dead wood carbon budget are decay rates, which may vary with the type of wood and microclimatic conditions, and site preparation procedures (e.g. controlled broadcast burning, or burning of piles). Equation 3.2.12 can be used with sample data obtained consistent with the principles set out in Section 5.3. Table 3.2.2 provides data which may be useful for model intercomparison, but are not suitable as defaults.

TABLE 3.2.2
UPDATED DEFAULTS OF NATURAL MORTALITY RATES, DEAD WOOD STOCKS, AND LIVE:DEAD RATIOS
(Note that these are mostly based on semi natural and near natural forests)

Biome[a]	**Average mortality rate (fraction of standing biomass per year)**	**Coefficient of Variation/Number of stands**
Tropical forest	0.0177	0.616/61
Evergreen forest	0.0116	1.059/49
Deciduous forest	0.0117	0.682/29
	Average (median) dead wood stock (tonnes d.m. ha^{-1})	**Coefficient of Variation/Number of stands**
Tropical forest	18.2	2.12/37
Evergreen forest	43.4	1.12/64
Deciduous forest	34.7	1.00/62
	Average (median) dead:live ratio	**Coefficient of Variation/Number of stands**
Tropical forest	0.11	0.75/10
Evergreen forest	0.20	1.33/18
Deciduous forest	0.14	0.77/19

Sources: Harmon, M. E., O. N. Krankina, M. Yatskov, and E. Matthews. 2001. Predicting broad-scale carbon stores of woody detritus from plot-level data. Pp. 533-552 In: Lal, R., J. Kimble, B. A. Stewart, Assessment Methods for Soil Carbon, CRC Press, New York

[a] For delineation of biomes, see Figure 3.1.3.

LITTER

Tier 1 (Default): In the *IPCC Guidelines*, consistent with reporting under Tier 1, litter inputs and outputs are assumed to balance and the pools are therefore taken to be stable. Countries experiencing significant changes in forest types or disturbance or management regimes in their forests are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies. Default values are presented in Table 3.2.1. These values may be used as an approximate calculation to determine if litter carbon is a key category, or as a check for country-specific values.

Tier 2: It is *good practice* to use country level data on litter for different forest categories, in combination with default values if country or regional values are not available for some forest categories. Table 3.2.1 provides updated default data on litter stocks, but these are not a substitute for national data, where available.

Tier 3: National level disaggregated litter carbon estimates are available for different forest types, disturbance and management regimes, based on measurements from National Forest Inventories or from a dedicated greenhouse gas (GHG) Inventory Programme.

3.2.1.2.1.3 Choice of Activity Data

Activity data consist of areas of forest remaining forest summarised by major forest types, management practices, and disturbance regimes. Total forest area should be consistent with those reported under other sections of this chapter, notably Section 3.2.1.1. The assessment of changes in dead organic matter is greatly facilitated if this information can be used in conjunction with national soil and climate data, vegetation inventories, and other geophysical data. The area summaries for the litter pool may be different than those for the dead wood pool when it is known that emission factors do not vary for some of the activity data, such as by management practice.

Data sources will vary according to a country's forest management system, from individual contractors or companies, to regulation bodies and government agencies responsible for forest inventory and management, and research institutions. Data formats vary widely, and include, among others, activity reports submitted regularly within incentive programs or as required by regulations, forest management inventories and remotely sensed imagery.

3.2.1.2.1.4 Uncertainty Assessment

The uncertainty associated with Tier 1 methods is so high that the dead organic matter pools were simply assumed to be stable at a time that managed forests are growing. Logging residue created by harvest was assumed to decay instantly at time of harvest, emitting its entire mass as carbon dioxide. Emissions from dead organic matter due to disturbances like wildfires, or insect or disease infestation were ignored. The dynamics of the litter carbon pool were also ignored. When emissions are assumed equal to zero, describing uncertainty in terms of percentage of the emissions is indeterminate. Any percentage multiplied by zero is zero.

DEAD WOOD

An estimate for a maximum bound for carbon in dead wood is 25% of the amount of C in live biomass pools. The maximum value in absolute terms in C in dead wood is 25% of the amount of C in live biomass pools divided by five. Dividing by 5 simulates dead wood decaying in five years. The use of regional and country-specific inventory data and models under Tiers 2 and 3 enables for significant reduction of uncertainties. A survey of dead wood may be designed for any designated precision. Nationally determined values of within ±30% may be reasonable for dead wood.

LITTER

Ranges in Table 3.2.1 may be analyzed for uncertainty defaults for litter. For litter pools, the uncertainty is approximately a factor of one. For emissions or sequestration rates, the uncertainty is also approximately a factor of one. The use of regional and country-specific inventory data and models under Tiers 2 and 3 enables for significant reduction of uncertainties.

3.2.1.3 CHANGE IN CARBON STOCKS IN SOILS

This section elaborates on estimation procedures and *good practices* for estimating change in carbon stocks from and to forest soils. Separate guidance is provided for two types of forest soil carbon pools: 1) the organic fraction of mineral forest soils, and 2) organic soils. The change in carbon stocks in soils in forest land remaining forest land ($\Delta C_{FF_{Soils}}$) is equal to the sum of changes in carbon stocks in the mineral soil ($\Delta C_{FF_{Mineral}}$) and the organic soil ($\Delta C_{FF_{Organic}}$).

This report does not address the inorganic soil carbon pool, but notes the need for soil analytical procedures to distinguish between the organic and inorganic fractions where the latter is significant.

SOIL ORGANIC MATTER

Soil organic matter refers to a complex of large and amorphous organic molecules and particles derived from the humification of aboveground and belowground litter, and incorporated into the soil, either as free particles or bound to mineral soil particles. It also includes organic acids, dead and living microorganisms, and the substances synthesized from their breakdown products (Johnson *et al.*, 1995).

It is *good practice* to separate mineral from organic forest soils, as default estimation procedures are different.

SOIL ORGANIC MATTER IN MINERAL FOREST SOILS

Globally, the organic carbon content of mineral forest soils (to 1 m depth) varies between less than 10 and almost 20 kg C m^{-2}, with large standard deviations (Jobbagy and Jackson, 2000). Mineral forest soils to that depth contain approximately 700 Pg C (Dixon *et al.*, 1994). Because the input of organic matter is largely from aboveground litter, forest soil organic matter tends to concentrate in the upper soil horizons, with roughly half of the soil organic carbon of the top 100 cm of mineral soil being held in the upper 30 cm layer. The carbon held in the upper profile is often the most chemically decomposable, and the most directly exposed to natural and anthropogenic disturbances.

Due to inconsistent classifications, there is no global estimate of the carbon content of forested organic soils. Zoltai and Martikainen (1997) estimated that forested peatlands extend between 70 and 88 Mha (using a 30 cm minimum depth), with a global carbon content in the order of 500 Pg.

BOX 3.2.1
ORGANIC SOILS, PEATLANDS AND WETLANDS

The expressions organic soils and peatlands are sometimes used interchangeably in the literature, although the term “peat”, more commonly used in the ecological literature, really refers to the origin of the organic material – principally moss fragments formed under anaerobic conditions. The mere presence of peat is not sufficient to define the soil as organic. Note that organic soils may be covered by LFH (litter, fermentation and humus) layers, however these organic layers would not be found in an anaerobic environment.

Wetlands are identified and classified based on their hydrological properties, i.e. by the dominance of anaerobic conditions. Bogs are wetlands with an organic substrate.

For the purpose of this document, all organic soils within the managed forest should be included in the assessment, regardless of the origin of the organic matter, or the soil’s hydrological regime.

3.2.1.3.1 METHODOLOGICAL ISSUES

Soil organic matter is in a state of dynamic balance between inputs and outputs of organic carbon. Inputs are largely determined by the forest productivity, the decomposition of litter and its incorporation into the mineral soil; rates of organic matter decay and the return of carbon to the atmosphere through respiration control outputs (Pregitzer, 2003). Other losses of soil organic carbon occur through erosion or the dissolution of organic carbon, but these processes may not result in immediate carbon emissions.

In general, human activities and other disturbances alter the carbon dynamics of forest soils. Changes in forest type, productivity, decay rates and disturbances can effectively modify the carbon contents of forest soils. Different forest management activities, such as rotation length; harvest practices (whole tree or sawlog; regeneration, partial cut or thinning); site preparation activities (prescribed fires, soil scarification); and fertilisation, interfere more or less strongly with soil organic carbon (Harmon and Marks, 2002; Liski *et al.*, 2001; Johnson and Curtis, 2001). Changes in disturbance regimes, notably in the occurrence of severe forest fires, pest outbreaks, and other stand-replacing disturbances are also expected to alter the forest soil carbon pool (Li and Apps, 2002; de Groot *et al.*, 2002).

MINERAL SOILS

In spite of a growing body of literature on the effect of forest types, management practices and other disturbances on soil organic carbon, the available evidence remains largely site- and study-specific, for the most part influenced by climatic conditions, soil properties, the time scale of interest, the soil depth considered and the sampling intensity (Johnson and Curtis, 2001; Hoover, 2003; Page-Dumroese *et al.*, 2003). The current knowledge remains inconclusive on both the magnitude and direction of carbon stock changes in mineral forest soils associated with forest type, management and other disturbances, and cannot support broad generalisations.

The proposed approach acknowledges the regionally important impact of forest type, management activities or disturbance regimes on the carbon budget of mineral forest soils, and allows for the incorporation of the available scientific knowledge and data. However, due to the incomplete scientific basis and resulting uncertainty, the assumption in the *IPCC Guidelines* that forest soil carbon stocks remain constant is retained and accordingly no default data will be provided at the Tier 1 level.

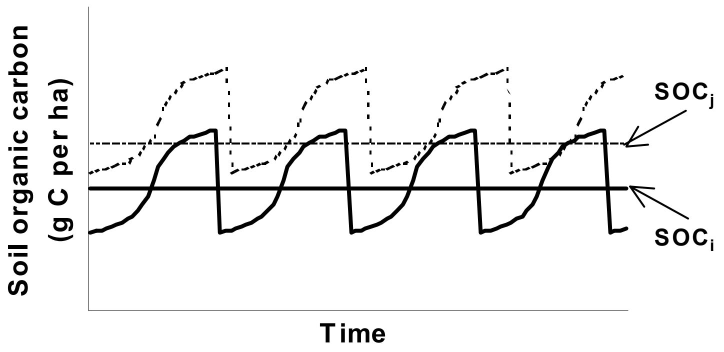
Conceptually, the default approach assumes a stable, spatially-averaged carbon content of mineral soils under given forest types, management practices and disturbance regimes. This equilibrium value is altered when these states or conditions change. The following assumptions are made:

(i) Forest soil organic carbon (SOC) reaches over time a spatially-averaged, stable value specific to the soil, forest type and management practices (e.g. tropical conifer plantation on a low-activity soil). This value is a temporally averaged SOC best estimated over several rotations or disturbance cycles (Figure 3.2.1).

(ii) Changes in forest type or management leading to a new stable SOC value occur over a transition time equal to the length of a rotation or the return interval of natural disturbances, in years.

(iii) SOC sequestration/release during the transition to a new equilibrium SOC occurs in a linear fashion.

Figure 3.2.1 Two temporally averaged values of soil organic carbon corresponding to different combinations of forest soils, management practices and disturbance regimes.



ORGANIC SOILS

As in mineral soils, the accumulation or loss of carbon in organic soils results from a balance between inputs and outputs. When wet or moist conditions more or less hamper the decomposition of organic matter, input of organic matter may exceed decomposition losses, and organic matter accumulates. The carbon released from saturated organic soils to the atmosphere is predominantly under the form of CH_4, while under aerobic conditions the C flux to the atmosphere is dominated by CO_2. The C dynamics of organic soils are closely linked to the site hydrological regimes: available moisture, depth of the water table, reduction-oxidation conditions (Clymo, 1984; Thormann *et al.*, 1999); but also species composition and litter chemistry (Yavitt *et al.*, 1997). This C pool will readily respond to activities or events that affect aeration and decomposition conditions.

The drainage of organic soils releases CO_2 by oxidation of the organic matter in the aerobic layer, although this loss of carbon can be partially or entirely offset by: 1) greater inputs of organic matter from above; or 2) decrease in natural fluxes of CH_4. The magnitude of the CO_2 emissions is related to drainage depth, the fertility and consistence of the peat, and temperature (Martikainen *et al.*, 1995). Abandonment of drainage in organic soils reduces these CO_2 emissions and may even re-establish the net carbon sequestration potential in forested organic soils (see also Section 3a.3.2 (Organic soils managed for peat extraction) in Appendix 3a.3, and Section 3.2.1.4 (Non-CO_2 Greenhouse Gas Emissions)). The CO_2 released from organic matter oxidation after drainage is considered anthropogenic. Emissions from undrained, and unmanaged forested peatlands are considered as natural and are therefore not accounted for.

Other forest management activities are likely to disrupt the C dynamics of the underlying organic soils. Harvest, for example, may cause a rise in the water table due to reduced interception, evaporation and transpiration (Dubé *et al.*, 1995).

While there is some evidence of the effects of anthropogenic activities on forested organic soils, the data and knowledge remain largely site-specific and can hardly be generalized. The net carbon flux of organic soils is usually directly estimated from chamber or flux tower measurements (Lafleur, 2002).

3.2.1.3.1.1 Choice of Method

Calculation procedure for change in carbon stocks in soils

MINERAL SOILS

Conceptually, emissions or removals of carbon from the mineral forest soil pool can be calculated as annual changes in soil organic carbon stocks for an area of forest land undergoing a transition from state *i* to state *j*, where each state corresponds to a given combination of forest type, management intensity and disturbance regime. This is illustrated by Equation 3.2.14:

EQUATION 3.2.14

ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS IN FOREST LAND REMAINING FOREST LAND

$$\Delta C_{FF_{MINERAL}} = \Sigma_{ij} \left[(SOC_j - SOC_i) \bullet A_{ij} \right] / T_{ij}$$

Where,

$$SOC_i = SOC_{ref} \bullet f_{forest\ type\ (i)} \bullet f_{man\ intensity\ (i)} \bullet f_{dist\ regime\ (i)}$$

Where:

$\Delta C_{FF_{Mineral}}$ = annual change in carbon stocks in mineral soils in forest land remaining forest land, tonnes C yr^{-1}

SOC_i = stable soil organic carbon stock, under previous state *i*, tonnes C ha^{-1}

SOC_j = stable soil organic carbon stock, under current state *j*, tonnes C ha^{-1}

A_{ij} = forest area undergoing a transition from state *i* to *j*, ha

T_{ij} = time period of the transition from SOC_i to SOC_j, yr. The default is 20 years.

SOC_{ref} = the reference carbon stock, under native, unmanaged forest on a given soil, tonnes C ha^{-1}

$f_{forest\ type\ (i)}$ = adjustment factor reflecting the effect of a change from the native forest to forest type in state *i*, dimensionless

$f_{man\ intensity\ (i)}$ = adjustment factor reflecting the effect of management intensity or practices on forest in state *i*, dimensionless

$f_{dist\ regime\ (i)}$ = adjustment factor reflecting the effect of a change in the disturbance regime to state *i* with respect to the native forest, dimensionless

The transition from SOC_i to SOC_j is assumed to take place over a transition period of T years (default = 20 years). In other words $\Delta C > 0$ as long as fewer than T years have elapsed since the onset of changes in forest type, management practices, or disturbance regime. The total SOC changes in any year equals the sum of the annual emissions/removals for all forest lands having undergone changes in forest types, management practices or disturbance regimes for a period of time shorter than T years.

The decision tree in Figure 3.1.1 (Section 3.1) provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures.

Tier 1: This tier is used for countries using the default procedure in the *IPCC Guidelines*, or for which this subcategory is not significant, and little or no country-specific data exist on the SOC of mineral forest soils under dominant forest types, management practices and disturbance regimes. Under Tier 1, it is assumed that when forest remains forest the carbon stock in soil organic matter does not change, regardless of changes in forest management, types, and disturbance regimes (i.e. $SOC_j = SOC_i = \ldots = SOC_n$) in other words that the carbon stock in mineral soil remains constant so long as the land remains forest.

Tier 2: Countries where this subcategory is significant should develop or select representative adjustment factors $f_{forest\ type}$, $f_{man\ intensity}$, and $f_{dist\ regime}$ reflecting the impact on mineral SOC of different forest types, management practices or disturbance regimes, and SOC_{ref} for their own native, unmanaged forest ecosystems. Domestic values for the transition period T should be developed, and the assumption of linear rates of SOC change can be modified to better reflect the actual temporal dynamics of soil carbon sequestration or release.

Tier 3: Tier 3 is appropriate for countries where emissions/removals in the mineral soils of managed forests are important, while current knowledge and available data allow the development of an accurate and comprehensive domestic estimation methodology. This involves the development, validation and implementation of a domestic monitoring scheme and/or modelling tool and its associated parameters. The basic elements of any country-specific approach are (adapted from Webbnet Land Resource Services Pty ltd, 1999):

- Stratification by climatic zones, major forest types and management regimes coherent with those used for other sections of the inventory, especially the other carbon pools under this Section 3.2.1;
- Determination of dominant soil types in each stratum;
- Characterisation of corresponding soil carbon pools, identification of determinant processes in SOC input and output rates and the conditions under which these processes occur; and
- Determination and implementation of suitable methods to estimate carbon emissions/removals from forest soils for each stratum on an operational basis, including validation procedures; methodological considerations should include the combination of monitoring activities – such as repeated forest soil inventories - and modelling studies, and the establishment of benchmark sites. Further guidance on good soil monitoring practices is available in the scientific literature (Kimble *et al.*, 2003; Lal *et al.*, 2001; McKenzie *et al.*, 2000), and Section 5.3 provides generic guidance on sampling techniques. Models developed or adapted for this purpose should be peer-reviewed, and validated with observations representative of the ecosystems under study and independent from the calibration data.

The methodology should be comprehensive, and include all managed forest lands and all anthropogenic influence on SOC dynamics. Some assumptions underlying Tier 3 estimation procedures may depart from those inherent to the default methodology, provided sound scientific basis underlies new assumptions. Tier 3 may also include factors that influence emissions and removals of C from forest soils that are not included in the default approach. Finally, Tier 3 calculations are expected to be more refined temporally and spatially. It is *good practice*, at Tier-3 accounting level, to include SOC in an integrated ecosystem assessment of all forest carbon pools, with explicit linkages between the soil, biomass and dead organic matter pools.

The national methodology should include a strong verification component, in which independent data are collected for the verification of the applicability of defaults values and national parameters. Verification activities should take place at a number of spatial and temporal scales, and may incorporate data from basic inventory methods, remote sensing and modelling. Chapter 5 elaborates on general approaches to the verification of inventory estimates.

ORGANIC SOILS

Current knowledge and data limitations constrain the development of a default methodology for estimating CO_2 emissions to and from drained, organic forest soils. Guidance will be limited to the estimation of carbon emissions associated with the drainage of organic soils in managed forests (Equation 3.2.15).

EQUATION 3.2.15
CO_2 EMISSIONS FROM DRAINED ORGANIC FOREST SOILS

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

Where:

$\Delta C_{FF_{Organic}}$ = CO_2 emissions from drained organic forest soils, tonnes C yr^{-1}

$A_{Drained}$ = area of drained organic forest soils, ha

$EF_{Drainage}$ = emission factor for CO_2 from drained organic forest soils, tonnes C ha^{-1} yr^{-1} (see Table 3.2.3)

TABLE 3.2.3
DEFAULT VALUES FOR CO_2-C EMISSION FACTOR FOR DRAINED ORGANIC SOILS IN MANAGED FORESTS

Biomes	Emissions factors (tonnes C ha^{-1} yr^{-1})	
	Values	Ranges
Tropical forests	1.36	0.82 – 3.82
Temperate forests	0.68	0.41 – 1.91
Boreal forests	0.16	0.08 – 1.09

Emissions are assumed to continue for as long as the aerobic organic layer remains and the soil is considered to be an organic soil.

Tier 1: Tier 1 calculation procedures involve producing country-specific data on the area of drained, organic forest soils and applying the appropriate default emissions factor. This tier is appropriate for countries in which this subcategory is not significant, and in case where representative $EF_{Drainage}$ values are not available.

Tier 2: Tier 2 is suitable for countries where this subcategory is significant; these countries should develop or select representative $EF_{Drainage}$ values.

Tier 3: Tier 3 methodology involves the estimation of CO_2-C emissions and removals associated with the entire area of forested organic soils, including all anthropogenic activities likely to alter the hydrological regime, surface temperature and vegetation composition of forested organic soils; and major disturbances such as fires. It is *good practice*, in Tier 3 estimation procedures, to conduct a full carbon balance of forested organic soils, including fluxes of both CO_2 and CH_4. Tier 3 methodologies should also be consistent with the estimation procedures for non-CO_2 GHG in Section 3.2.1.4. Tier 3 estimation procedures are appropriate if a country's managed forest includes extensive areas of organic soils.

Figure 3.1.1 (Section 3.1) provides guidance in the selection of tiers for the estimation of CO_2 emissions from drained, organic forest soils.

3.2.1.3.1.2 Choice of Emission/Removal Factors

MINERAL SOILS

The parameters to be estimated are $SOC_{i,j}$, T_{ij}, SOC_{ref} , $f_{forest\ type}$, $f_{man\ intensity}$, and $f_{dist\ regime}$.

Tier 1: The current state of knowledge on managed forest soils does not allow the derivation of default soil carbon stock parameters ($SOC_{i,j}$). Default values for SOC_{ref}, the organic carbon content of mineral forest soils under native vegetation, for 0-30 cm depth, are provided in Table 3.2.4.

Tier 2: Countries provide their own values of SOC_{ref}, compiled from published studies or surveys representative of major native forest and soil types. Such values are typically obtained through the development and/or compilation of large soil profile databases (Scott *et al.*, 2002; NSSC, 1997; Siltanen *et al.*, 1997).

The carbon content per unit area (or carbon stocks) should be reported in tonnes C ha^{-1} for a given soil depth or layer (e.g. to 100 cm, or for the 0-30 cm layer). As shown in Equation 3.2.16, total SOC contents is obtained by summing the SOC contents of the constituent soil horizons or layers; the SOC content of each horizon or layer is calculated by multiplying the concentration of soil organic carbon in a sample (g C (kg soil)$^{-1}$), with the corresponding depth and bulk density (Mg m^{-3}) and adjusting for the soil volume occupied by coarse fragments:

Table 3.2.4
Default reference (under native vegetation) soil organic C stocks (SOC_{REF})
(tonnes C per ha for 0-30 cm depth)

Region	HAC soils[1]	LAC soils[2]	Sandy soils[3]	Spodic soils[4]	Volcanic soils[5]	Wetlands soils[6]
Boreal	68	NA	10#	117	20#	146
Cold temperate, dry	50	33	34	NA	20#	87
Cold temperate, moist	95	85	71	115	130	
Warm temperate, dry	38	24	19	NA	70#	88
Warm temperate, moist	88	63	34	NA	80	
Tropical, dry	38	35	31	NA	50#	86
Tropical, moist	65	47	39	NA	70#	
Tropical, wet	44	60	66	NA	130#	

Note: Data are derived from soil databases described by Jobbagy and Jackson (2000) and Bernoux *et al.* (2002). Mean stocks are shown. A default error estimate of 95% (expressed as 2X standard deviations as percent of the mean are assumed for soil-climate types. NA denotes 'not applicable' because these soils do not normally occur in some climate zones.

# indicates where no data were available and default values from *IPCC Guidelines* were retained.

[1] Soils with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals (in the World Reference Base for Soil Resources (WRB) classification these include Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols; in USDA classification includes Mollisols, Vertisols, high-base status Alfisols, Aridisols, Inceptisols).

[2] Soils with low activity clay (LAC) minerals are highly weathered soils, dominated by 1:1 clay minerals and amorphous iron and aluminium oxides (in WRB classification includes Acrisols, Lixisols, Nitisols, Ferralsols, Durisols; in USDA classification includes Ultisols, Oxisols, acidic Alfisols).

[3] Includes all soils (regardless of taxonomic classification) having > 70% sand and < 8% clay, based on standard textural analyses (in WRB classification includes Arenosols,; in USDA classification includes Psamments).

[4] Soils exhibiting strong podzolization (in WRB classification includes Podzols; in USDA classification Spodosols)

[5] Soils derived from volcanic ash with allophanic mineralogy (in WRB classification Andosols; in USDA classification Andisols)

[6] Soils with restricted drainage leading to periodic flooding and anaerobic conditions (in WRB classification Gleysols; in USDA classification Aquic suborders).

Equation 3.2.16
Soil organic carbon content

$$SOC = \sum_{horizon=1}^{horizon=n} SOC_{horizon} = \sum_{horizon=1}^{horizon=n} \left([SOC] \bullet BulkDensity \bullet Depth \bullet (1 - frag) \bullet 10 \right)_{horizon}$$

Where:

SOC = representative soil organic carbon content for the forest type and soil of interest, tonnes C ha^{-1}

$SOC_{horizon}$ = soil organic carbon content for a constituent soil horizon, tonnes C ha^{-1}

[SOC] = concentration of soil organic carbon in a given soil mass obtained from lab analyses, g C (kg soil)$^{-1}$

Bulk Density = soil mass per sample volume, tonnes soil m^{-3} (equivalent to Mg m^{-3})

Depth = horizon depth or thickness of soil layer, m

frag = % volume of coarse fragments/100, dimensionless [2]

Country- or region-specific values should be elaborated for the stable SOC_i, SOC_j, for the major combinations of forest types, management practices and disturbance regimes. Priority should be given to the factors that have the

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[2] [SOC] is usually determined on the fine earth fraction (commonly < 2 mm). The bulk density should be corrected for the proportion of the soil volume occupied by coarse fragments (e.g. particles with a diameter > 2 mm).

largest overall effect, taking into account the impact on forest SOC and the extent of affected forests. Management practices can be coarsely labelled as intensive (e.g. plantation forestry with intensive site preparation and fertilisation) or extensive (natural forests with minimum intervention); these categories can also be redefined according to national circumstances. The development of adjustment factors is likely to be based on intensive studies at experimental sites and sampling plots involving replicated, paired site comparisons (Johnson *et al.*, 2002; Olsson *et al.*, 1996; see also the reviews by Johnson & Curtis, 2001 and Hoover, 2003.) In practice, it may not be always possible to separate the effects of a different forest types, intensive management practices and altered disturbance regimes, in which case some adjustment factors can be combined into a single modifier. If a country has well-documented data for different forest types under different management regimes it might be possible to derive SOC_i directly without using reference carbon stocks and adjustment factors. Estimating the effect of changing disturbance regimes over vast areas through sampling studies may create intractable logistical problems. Modelling studies provide an alternative approach for the derivation of these adjustment factors (Bhatti *et al.*, 2001).

The duration of transition periods T between stable SOC_i can be estimated from long-term monitoring of changes in forest SOC. The assumption of a linear rate of carbon stock changes during the transition from one forest type/management regime to another can also be reassessed.

Tier 3: Country-specific methodologies and parameters are expected to be based on rigorous monitoring programs, coupled with empirical and/or process modelling studies. The national system must represent all significant forest types, management practices and disturbance regimes. Models must be validated with independent observations from country or region-specific studies that cover the range of climatic conditions, soil types and management practices. The same quality criteria as described under Tier 2 apply to SOC data. Documentation on the structure, update frequency and procedures, and QA/QC procedures of SOC databases should also be available.

ORGANIC SOILS

The parameters to be estimated are emission factor(s) for CO_2 from drained organic forest soils: $EF_{Drainage}$.

Tier 1: Table 3.2.3 provides default values for $EF_{Drainage}$, derived from corresponding values for the conversion to pastures/forests in the *IPCC Guidelines*, (Reference Manual, Section 5.3.9). These values apply for as long as a drained organic soil remains.

Tier 2: Countries which develop their own emission factors or adopt ones that are different from the default values should provide scientifically-based evidence of their reliability and representativeness, document the experimental procedures used to derive them, and provide uncertainty estimates.

3.2.1.3.1.3 Choice of Activity Data

It is *good practice* to distinguish managed forests on mineral soils from those on organic soils. The defining criteria of organic soils are provided in the Glossary. For the purpose of this assessment, the depth of the organic layer itself is not as important as its presence; countries are therefore encouraged to use their own national depth criterion for the distinction between organic and mineral soils. Mineral soils comprised all soils which do not fulfill the definition of organic soils.

Forest inventories, where they include soil descriptions, are preferred data sources. Statistical, stratified sampling programmes can provide an estimate of the proportion of the managed forest on organic soils, but will not indicate their location. However, it is an acceptable first step in the determination of the importance of forested organic soils. Alternatively, an area estimate of forest on organic soils could be derived from overlaying soil maps, and land cover or land use maps. However the relative uncertainty associated with this type of GIS exercise is high, since it combines the omission and commission errors of all the maps used. Standard GIS textbooks provide guidance on the treatment of error for overlay exercises.

MINERAL SOILS

Tier 2: Activity data consist of the major forest types, management practices, disturbance regimes and the areas to which they apply, consistently with the guidance provided in Chapter 2 of the present report. The data should preferably be linked to the national forest inventory, where one exists, or with national soil and climate databases.

Typical changes are: conversion of unmanaged to managed forest; conversion of native forest into a new forest type; intensification of forest management activities, such as site preparation, tree planting and shorter rotations; changes in harvesting practices (bole vs. whole-tree harvesting; amount of residues left on-site); frequency of disturbances (pest and disease outbreaks, flooding, fires etc). Data sources will vary according to a country's forest management system, but could include individual contractors or companies, statutory forest authorities, research institutions and agencies responsible for forest inventories. Data formats vary widely, and include, among others, activity reports, forest management inventories and remotely sensed imagery.

Records should extend sufficiently far back as to include all significant changes having occurred over the T years selected as the transition period, or else back-casting will be necessary.

Tier 3: It is *good practice* to adopt the same forest types, management practices and disturbance regimes as those used for estimating emissions/removals in other forest pools.

ORGANIC SOILS

The activity data consist of $A_{Drainage}$, the area of drained organic soil (including peatland) covered by forest. Probable data sources are forest management records of industry or statutory forest authorities. Alternatively, expert knowledge from within such organisations may be solicited.

3.2.1.3.1.4 Uncertainty Assessment

MINERAL SOILS

The greatest uncertainty arises from the determination of SOC values (in tonnes C ha^{-1}) over large areas (Equation 3.2.14). Default values have a high inherent uncertainty when applied to specific countries. Standard deviations of default reference soil carbon stocks under native vegetation are provided in Table 3.2.4.

For countries developing their own SOC values, the two major sources of uncertainty are soil bulk density and soil volume occupied by coarse fragments. When computing forest SOC values, assume 40% uncertainty in bulk density values, and a factor of 2 uncertainty for the soil volume occupied by coarse fragments. Assume that the top 30 cm of mineral forest soils contain 50% of total SOC. Uncertainty associated with shallow sampling can be reduced by providing scientific evidence on (1) the proportion of total SOC contained in the soil depth sampled; and (2) the depth at which SOC responds to changes in forest types, management practices and disturbance regimes. Chapter 5, Box 5.2.4, provides generic guidance on the treatment of uncertainty when estimates are derived from model outputs.

ORGANIC SOILS

The largest uncertainties stem from CO_2 emission factors for drained organic soils. Assume that $EF_{Drainage}$ varies by a factor of 2. The measurement of carbon stocks on organic soils present a significant challenge because of the great variability in bulk density (from 0.05 to 0.2 g cm^3, a four-fold difference), and in the total depth of the organic layer (an even large source of variability). Further uncertainty arises due to the failure of carbon stock changes to distinguish between off-site transfer of carbon as dissolved organic matter versus emissions to the atmosphere.

3.2.1.4 NON-CO_2 GREENHOUSE GAS EMISSIONS

This section considers N_2O emissions from forest soils and non-CO_2 greenhouse gas emissions from biomass burning. N_2O and NO_x are mainly produced in soils as a byproduct of nitrification and denitrification. Emissions are stimulated directly by N fertilisation of forests and drainage of wet forest soils (Appendix 3a.2), and indirectly through deposition of N from the atmosphere and leaching and runoff. The indirect N_2O emissions are addressed in the Agriculture Chapter of the *IPCC Guidelines* and therefore not considered here in order to avoid double counting. Liming of forest soil may reduce N_2O emissions in some environments, but increase emissions in others (Klemedtsson *et al.*, 1997, Mosier *et al.*, 1998, Papen and Butterbach-Bahl, 1999). Forest management such as clear cutting and thinning may increase N_2O emissions. However, available data are insufficient and somewhat contradictory, therefore in the present section the impact of these practices is not considered.

Afforestation with N-fixing tree species may increase N_2O emissions for much of the lifetime of the forest, but there is too limited data to provide a default methodology.

The CH_4 sink in aerated and undisturbed forest soils is a natural process and is estimated to average at 2.4 kg CH_4/ha/yr (Smith *et al.*, 2000). Forest management, particularly N fertilisation, may significantly alter this CH_4 sink. Methods and data to estimate changes in methane oxidation are not provided at this time. As additional information becomes available, a fuller consideration of various activities and their impacts on methane oxidation from fertilised lands may be possible.

NITROUS OXIDE

The *IPCC Guidelines* in Chapter 4 Agriculture include N_2O emissions from nitrogen fertilisation and also account for N_2O emissions from nitrogen deposition as “indirect N_2O emissions”. Specific guidance is given below applying the methods from Chapter 4 of the *IPCC Guidelines* to estimate fertiliser-based N_2O emissions from forests. The methodology for estimating N_2O emissions from drainage of wet forest soils is presented in Appendix 3a.2. Forests receive atmospheric nitrogen depositions and nitrogen in runoff and leaching from adjacent agricultural fields. The Agriculture Chapter of the *IPCC Guidelines* already addresses these N_2O emissions from N deposition, runoff and leaching as “indirect emissions”. These emissions are not accounted here, avoiding double-counting. It is assumed that the leaching and run-off from forests where nitrogen fertiliser is applied into surrounding non-forest or unfertilised forest areas is negligible. This is justified because leaching and runoff are smaller in forest than in agricultural land, and the emission factor used in the *IPCC Guidelines* appears to be high.

3.2.1.4.1 METHODOLOGICAL ISSUES

The method used to estimate N_2O emissions from forest soils is identical to that provided in the *IPCC Guidelines* for Agriculture and described in *GPG2000*. The basic equation, taken from *GPG2000*, is shown in Equation 3.2.17.

EQUATION 3.2.17
DIRECT N_2O EMISSIONS FROM MANAGED FORESTS

$$N_2O\ direct\text{-}N_{FF} = (N_2O\ direct\text{-}N_{fertiliser} + N_2O\ direct\text{-}N_{drainage})$$

Where:

N_2O direct-N_{FF} = direct emissions of N_2O from managed forests in units of Nitrogen, Gg N

N_2O direct-$N_{fertiliser}$ = direct emissions of N_2O from forest fertilisation in units of Nitrogen, Gg N

N_2O direct-$N_{drainage}$ = direct emissions of N_2O from drainage of wet forest soils in units of Nitrogen, Gg N

The method for estimating N_2O emissions from fertiliser application to forest is described in Equation 3.2.18 in the sections below. The method for estimating N_2O emissions from drainage of wet forest soils is described in Appendix 3a.2 and may be applied optionally where data are available.

3.2.1.4.1.1 Choice of Method

Figure 3.1.1 provides the decision tree to select the respective tier for N_2O emissions from forest land. As shown in Equation 3.2.17, N_2O emissions include two sources: forest fertilisation and drainage of wet forest soils.

Tier 1: Emission rates are the same for N_2O fertilisation in forest and agricultural areas. Thus, *good practice* from *GPG2000* should be used to estimate N_2O emissions from nitrogen inputs as mineral or organic fertiliser to forests. N_2O emissions from manure deposited by animals grazing in forest areas are reported in Agricultural Soils part of the *IPCC Guidelines* Agriculture Chapter under Pasture/Range/Paddock emissions and should not be estimated separately in the forest section.

Direct N_2O emissions from forest fertilisation are calculated as in Equation 3.2.18:

EQUATION 3.2.18
DIRECT N_2O EMISSIONS FROM FOREST FERTILISATION

$$N_2O\ direct\text{-}N_{fertiliser} = (F_{SN} + F_{ON}) \bullet EF_1)$$

Where:

N_2O direct-$N_{fertiliser}$ = direct emissions of N_2O from forest fertilisation in units of Nitrogen, Gg N

F_{SN} = annual amount of synthetic fertiliser nitrogen applied to forest soils adjusted for volatilisation as NH_3 and NO_x, Gg N

F_{ON} = annual amount of organic fertiliser nitrogen applied to forest soils adjusted for volatilisation as NH_3 and NO_x, Gg N

EF_1 = emission factor for N_2O emissions from N inputs, kg N_2O-N / kg N input

In order to calculate N_2O emissions using this equation, the amounts of N inputs, F_{SN} and F_{ON} must be estimated. It is *good practice to* adjust for the amount that volatilises as NH_3 and NO_x, using the same volatilisation factors as in the agriculture chapter of the *IPCC Guidelines.* Indirect N_2O emissions from the N volatilised are calculated as in the agriculture chapter of the *IPCC Guidelines.*

Tier 2: Under Tier 2, country-specific information and additional management activities can be included in estimating nitrous oxide emissions:

Countries can use Equation 3.2.18 with an emission factor EF_1 developed to meet the specific conditions of the country. Specific *good practice guidance* on how to derive country-specific EFs is given in Box 4.1, Good Practice in Derivation of Country-Specific Emission Factors, page 4.62 of *GPG2000.* In addition, countries can extend the estimation to take into account the impact of forest liming and management (thinning, harvest) on N_2O emission. Liming can reduce N_2O emissions from forest in some environments and increase them in others.

Tier 3: Some models exist for estimating N_2O emissions (Renault, 1999, Conen *et al.*, 2000, Stange and Butterbach-Bahl, 2002). Apply advanced models capable of representing the impacts of management practices and other relevant driving variables. It is *good practice* to validate the models against measurements and to document thoroughly the model parameterization and calibration.

Most models calculate the total N_2O emissions which include more than the human-induced emissions. The direct human-induced emissions could be estimated by running the model with and without fertilisation and drainage, and using the difference as the direct human-induced component of the emissions.

3.2.1.4.1.2 Choice of Emission/Removal Factors

Tier 1: As noted in *GPG2000*, the default emission factor (EF_1) is 1.25 % of applied N, and this value should be used under Tier 1.

Tier 2: Countries may develop specific emission factors that are more appropriate for their countries. Specific *good practice guidance* on how to derive country-specific emission factors is given in Box 4.1, Good Practice in Derivation of Country-Specific Emission Factors, page 4.62 of *GPG2000.* The availability of country-specific factors is essential if the effects of liming and management are to be considered.

Tier 3: In case N_2O emission are estimated with models, it is necessary to make sure that the models distinguish between "indirect N_2O" from N deposition (covered in Agriculture Chapter of the *IPCC Guidelines*) and fertilisation. The PnET-N-DNDC model, for instance, is a process oriented model which is already applicable to estimate N_2O-emissions from forest soils (Butterbach-Bahl *et al.*, 2001; Li *et al.*, 2000).

3.2.1.4.1.3 Choice of Activity Data

N_2O emissions from managed forest are calculated on the basis of mineral and organic nitrogen inputs in forest soils. Some countries have data on fertilisation of forests separately from agriculture and will be able to make estimations. However, many countries may only have national fertiliser sales statistics. If such data are not available, countries may follow the guidance below to separate the amount applied to agricultural soils and forest soils, or they may report all emissions under Tier 1 in the agriculture sector. This should, however, be explicitly noted in the inventory.

F_{SN}: This is the same term used in the Agriculture Chapter of the *IPCC Guidelines* to refer to synthetic N applied to agricultural soils adjusted for the amount that volatilises as NH_3 and NO_x, using the same volatilisation factors as in the Agriculture Chapter of the *IPCC Guidelines.* Many countries have national fertiliser sales statistics. Countries can determine the amount of synthetic nitrogen fertiliser applied in forest by subtracting the amount of fertiliser used for agriculture from the national total nitrogen fertiliser applied. Alternatively, estimate fertiliser application in forests as the product of an estimated area of fertilised forest and an average fertilisation rate.

Countries being able to distinguish between fertiliser applied to newly planted forests versus old forests can use a Tier 2 level for estimating F_{SN}. For fertiliser applied to those forest plantations which have not yet reached canopy closure, the adjustment for volatilisation losses should follow the agriculture chapter of the *IPCC Guidelines*, i.e. taking account of the fraction of the N applied that is lost by volatilisation. For fertiliser applied to closed-canopy forests, it can be assumed that the adjustment is zero, i.e. all volatilised N is assumed to remain within the forest.

F_{ON}: Estimate organic nitrogen applied in forests from the tonnage of organic wastes spread in forest and their nitrogen content. Adjustment for volatilisation losses follows the guidance given for F_{SN}.

3.2.1.4.1.4 Uncertainty Assessment

Estimates of N_2O emissions from fertilisation of forests can be highly uncertain because of a) high spatial and temporal variability of the emissions, b) scarcity of long-term measurements and limited representativity of data for larger regions, and c) uncertainty in spatial aggregation and uncertainty inherent to the emission factors and activity data.

Tier 1: For EF_1, F_{SN} and F_{ON} , it is *good practice* to apply the uncertainty range applied in the agriculture source category unless more detailed analyses are available.

Emission factors: There are few measured data, mainly for boreal and temperate regions in Europe, on the effects of fertilisation, liming and forest management. Measured emission factors of N_2O have a skewed distribution, which is likely to be log-normal.

EF_1: Based on recent data (Smith *et al*., 1999; Mosier and Kroeze, 1999), *GPG2000* suggests the best estimate of uncertainties of EF_1 = 1.25% to range from 0.25% to 6%. The same uncertainty range is assumed for forest emissions.

***Activity data**:* If a country has separate statistics for fertiliser applied to forest and to agriculture, it can be assumed that the uncertainty in fertiliser statistics applied in forest is similar to the uncertainty in fertiliser statistics applied in agriculture. In this case, the same uncertainty is applied in both source categories, e.g. 10% or smaller for the amount of mineral fertiliser and 20% or smaller for the amount of organic waste (Chapter 4, Agriculture, of the *IPCC Guidelines*, and *GPG2000*). If a country derives the amount of fertiliser applied to forest and agriculture from a national total, an additional separate assessment of the uncertainty in the division is required. The total uncertainty will be country-specific and will probably be higher than in the separate statistics.

Tier 2: *Good practice* in derivation of country-specific emission factors is described in Box 4.1, Good Practice in Derivation of Country-Specific Emission Factors, page 4.62 of *GPG2000.*

Tier 3: Process-based models will probably provide a more realistic estimate but need to be calibrated and validated against measurements. Sufficient representative measurements are needed for validation purposes. Generic guidance on uncertainty assessment for advanced methods is given in Section 5.2, Identifying and Quantifying Uncertainties. Stange *et al.* (2000) have performed uncertainty assessment for the PnET-N-DNDC model. This can be taken as an example for how to proceed.

GREENHOUSE GAS EMISSIONS FROM BIOMASS BURNING

Biomass burning occurs in many types of land uses causing emissions of CO_2, CH_4, N_2O, CO, and NO_x. There are two general types of biomass burning covered in this section: burning within managed forests and burning in the course of land use conversion. The basic approach for estimating greenhouse gas emissions from biomass burning are the same regardless of the specific land use type. The basic approach is presented here and referenced in other relevant sections of this chapter (e.g., lands converted to croplands). This section provides *good practice guidance* for estimating emissions from biomass burning in:

- Forest land remaining Forest land;
- Land converted to Forest land;
- Land converted to Cropland; and
- Land converted to Grassland.

The *IPCC Guidelines* address both types of biomass burning in the LUCF sector (Chapter 5). Emissions from burning for land use conversion are covered under Forest and Grassland Conversions and emissions from burning for land management are covered under On-site burning of Forest Biomass. While presented separately in the *IPCC Guidelines*, the same method and default factors are used for estimating emissions. In this GPG, the methodology for emissions from burning for land conversion remains essentially unchanged from the *IPCC Guidelines*, but the scope of coverage of emissions from burning for land management is broadened in the case of managed forest land to include the effect of both prescribed and wildfires on CO_2 and non-CO_2 emissions in all managed forest lands.[3]

The *GPG2000* covers burning for land management in agriculture. Guidance is provided to estimate emissions from prescribed burning of savannas and field burning of agricultural residues covered under the Agricultural sector. The CO_2 released is assumed to be removed by photosynthesis of annual vegetation regrowing during the subsequent year and therefore only non-CO_2 gases are considered.

3.2.1.4.2 METHODOLOGICAL ISSUES

Generally fires can be grouped into prescribed (or controlled) fires and wildfires. Fires associated with land clearing and ecosystem management activities are usually controlled. Significant types of prescribed fires include: (i) land clearing fires in the course of forest conversion, (ii) slash-and-burn agriculture, (iii) post-logging burning of harvest residues (slash); and (iv) low-intensity prescribed fire for fuel load management. The purpose of these fires is usually to get rid of unwanted biomass. The average fire temperature is controlled, the burning conditions more uniform, and emission factors less variable. In contrast, the characteristics of wildfires are high variable: fire temperature, quantities of biomass available, thoroughness of the combustion and impact on forest

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[3] The elaboration is for forest land only because burning for land management in croplands and grasslands is covered by the Agriculture sector of the *GPG2000.*

stands all vary. Among wildfires, ground-level ones are less intensive and their impact on trees less severe than crown fires. When managed land is burned, emissions resulting from both prescribed fires and wildfires should be reported so that carbon losses on managed lands are taken into consideration.[4]

Estimating the impact of fire is more difficult for wildfires, especially high-temperature wildfires, than for controlled burns. As a consequence there is better knowledge on the effect of the latter than the former.

In managed forest, CO_2 emissions from combustion need to be estimated because the uptake of carbon by regrowing vegetation is taken into account (Kirschbaum, 2000) – see Equations 3.2.2 and 3.2.6. It is therefore *good practice* to estimate CO_2 and non-CO_2 emissions from biomass burning on managed forest lands. The method for doing this is set out in the parts of Section 3.2.1.1 dealing with Equation 3.2.9. The release of CO_2 in fire is not synchronous with the rate of uptake by regrowing forest and may take many years to sequester the quantity of carbon released in a wildfire or prescribed burn. If methods are applied that do not capture removals by regrowth after natural disturbances, then it is not necessary to report the CO_2 emissions associated with natural disturbance events. It is *good practice* to document this in a transparent manner.

The methodology described below can be used to estimate CH_4, N_2O, CO, and NO_x emissions from biomass burning on managed forest land and emissions of these gases from fires associated with land use conversions.

3.2.1.4.2.1 Choice of Method

The existing methodology described in the *IPCC Guidelines* estimates carbon release during fires as 50% (assuming this to be the C content of biomass) of the mass of fuel actually combusted and uses this as a basis for the calculation of non-CO_2 emissions (see Equation 3.2.6). Some of the partially burnt fuel remains as charcoal, which is relatively stable over time (Houghton, 1999).

Carbon release from burnt biomass as part of forest/grassland conversion is calculated using a simple methodology described in the *IPCC Guidelines* (Section 5.3). This methodology is extended below, for all vegetation types.

The emissions of non-CO_2 gases can be estimated based on the total carbon released using Equation 3.2.19 (Crutzen and Andreae, 1990; Andreae and Merlet, 2002):

EQUATION 3.2.19
ESTIMATION OF NON-CO_2 EMISSIONS FROM C RELEASED

$$CH_4 \text{ Emissions} = (\text{carbon released}) \bullet (\text{emission ratio}) \bullet 16/12$$

$$CO \text{ Emissions} = (\text{carbon released}) \bullet (\text{emission ratio}) \bullet 28/12$$

$$N_2O \text{ Emissions} = (\text{carbon released}) \bullet (\text{N/C ratio}) \bullet (\text{emission ratio}) \bullet 44/28$$

$$NO_x \text{ Emissions} = (\text{carbon released}) \bullet (\text{N/C ratio}) \bullet (\text{emission ratio}) \bullet 46/14$$

The extended methodology to estimate GHGs (CO_2 and non-CO_2) directly released in fires is summarised by the following equation:

EQUATION 3.2.20
ESTIMATION OF GHGS DIRECTLY RELEASED IN FIRES

$$L_{fire} = A \bullet B \bullet C \bullet D \bullet 10^{-6}$$

Where:

L_{fire} = quantity of GHG released due to fire, tonnes of GHG

A = area burnt, ha

B = mass of 'available' fuel, kg d.m. ha^{-1}

C = combustion efficiency (or fraction of the biomass combusted), dimensionless. (See Table 3A.1.12)

D = emission factor, g (kg d.m.)$^{-1}$

Calculations are made separately for each greenhouse gas, using the appropriate emission factor.

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[4] Fire impact in unmanaged forest lands should not be reported.

The accuracy of the estimates depends on the data available. Application of the decision tree in Figure 3.1.1 will determine which of the Tier 1 to 3 methods to use. Under Tier 1, the above two approaches can be used to estimates emissions for each GHG using default data. Under Tier 2, country-specific activity data or emission factors are used, while under Tier 3, both country-specific data and methods are used.

3.2.1.4.2.2 Choice of Removals/Emission Factors

Tier 1: Firstly, the quantity of fuel burnt must be estimated. If no local data are available, this can be estimated from Table 3.A.1.13 which tabulates the product of B (the available fuel, or biomass density on the land before combustion) and C (the combustion efficiency). If 'available fuel densities' are available the combustion efficiencies in Table 3.A.1.14 may be used. If combustion efficiency is needed, and more specific advice is not available, the IPCC default of 0.5 should be used. When the Equation 3.2.19 is used for the estimation of non-CO_2, an emission ratio and a N/C ratio is required. The N/C ratio for the fuel burnt is approximated to be about 0.01 (Crutzen and Andreae, 1990). This is a general default value that applies to leaf litter, but lower values would be appropriate for fuels with greater woody content, if data are available. Emission factors for use with Equations 3.2.19 and 3.2.20 are provided in Tables 3.A.1.15 and 3.A.1.16 respectively.

Tiers 2 and 3: Use country-specific data and methods developed through field experiments.

3.2.1.4.2.3 Choice of Activity Data

The selection of activity data should follow the guidance in Section 3.2.1.1 "Other Carbon Losses" for fires in managed forests.

Tier 1: Area of wild fire varies markedly between countries and over time. In extreme drought years, wild fires increase significantly. Thus, data on wild fires are highly country- and year- specific and cannot be generalized by region. A global data base exists on annual area of vegetation fires at: http://www.grid.unep.ch/activities /earlywarning/preview/ims/gba.

Tiers 2 and 3: Country level estimates of area burnt are used. These would generally be based on remotely-sensed methods.

3.2.1.4.2.4 Uncertainty Assessment

Tier 1: Estimates of non-CO_2 emissions from fires of forests can be highly uncertain because of: a) high spatial and temporal variability of the emissions, b) scarcity of measurements and limited representativeness of data for larger regions, and c) uncertainty in spatial aggregation and uncertainty inherent to the emission factors and activity data.

Emission factors: There are few measured data; it is suggested to apply a 70% uncertainty range in emission factors.

Activity data: Because of increased accuracy and global coverage of area burned by fire, uncertainty is relatively small, in the range of 20-30%.

Tier 2: Applying country-specific data to emission factors will greatly reduce uncertainty.

Tier 3: Process-based models will probably provide a more realistic estimate but need to be calibrated and validated against measurements. Sufficient representative measurements are needed for validation purposes.

3.2.2 Land Converted to Forest Land

Managed land is converted to forest land by afforestation and reforestation, either by natural or artificial regeneration (including plantations). These activities are covered under categories 5A, 5C, and 5D of *IPCC Guidelines*. The conversion involves a change in land use. This section does not provide any guidance on regeneration in unmanaged forests. Converted areas are considered forest if they correspond to definition of forest adopted by the country. Lands converted to forest land are followed in conversion status for 20 years[5]. After 20 years the areas are accounted for under Section 3.2.1 Forest land Remaining Forest land, although longer term dynamics of recovery may need tracking for up to about 100 years after establishment of forest.

The estimation of emissions and removals of carbon from land use conversions to forest land is divided into four sub-sections: Change in Carbon Stocks in Living Biomass (Section 3.2.2.1), Change in Carbon Stocks in Dead Organic Matter (Section 3.2.2.2), Change in Carbon Stocks in Soils (Section 3.2.2.3) and Non-CO_2 Greenhouse Gas Emissions (Section 3.2.2.4). Each sub-section provides pool-specific *good practice* approach for emission

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[5] The *IPCC Guidelines* specify default value of 20 years but allow for 100 years if necessary to take account of long term carbon dynamics in biomass, soil and litter pools.

and removal estimates. The CO_2 emissions or removals for land converted to forest are summarised by Equation 3.2.21:

EQUATION 3.2.21

ANNUAL CHANGE IN CARBON STOCKS IN LAND CONVERTED TO FOREST LAND [6]

$$\Delta C_{LF} = \Delta C_{LF_{LB}} + \Delta C_{LF_{DOM}} + \Delta C_{LF_{Soils}}$$

Where:

ΔC_{LF} = annual change in carbon stocks in land converted to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{LB}}$ = annual change in carbon stocks in living biomass (includes above- and belowground biomass) in land converted to forest land; tonnes C yr^{-1}

$\Delta C_{LF_{DOM}}$ = annual change in carbon stocks in dead organic matter (includes dead wood and litter) in land converted to forest land; tonnes C yr^{-1}

$\Delta C_{LF_{Soils}}$ = annual change in carbon stocks in soils in land converted to forest land; tonnes C yr^{-1}

To convert tonnes C to Gg CO_2, multiply the value by 44/12 and 10^{-3}. For the convention (signs), refer to Section 3.1.7 or Annex 3A.2 (Reporting Tables and Worksheets).

3.2.2.1 CHANGE IN CARBON STOCKS IN LIVING BIOMASS

3.2.2.1.1 METHODOLOGICAL ISSUES

This section presents *good practice* approach for calculation emissions and removals of CO_2 by changes in biomass on managed lands converted to forest land. This section covers the reporting categories of the *IPCC Guidelines* “Changes in Forest and Other Woody Biomass Stocks” and “Abandonment of Managed Lands” as applied to new forest land.

3.2.2.1.1.1 Choice of Method

Based on activity data and resources available, there are three tier methods that can be used by greenhouse gas inventory preparers to estimate changes in biomass stocks. The decision tree in Figure 3.1.2 illustrates *good practice* in choosing a method to calculate CO_2 removals and emissions in biomass on lands converted to forests.

Tier 1: Annual changes in carbon stocks in living biomass are estimated following default approach in the *IPCC Guidelines*. Changes in carbon stocks in living biomass on land converted to forest through artificial and natural regeneration are estimated with the use of Equation 3.2.22:

EQUATION 3.2.22

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

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

Where:

$\Delta C_{LF_{LB}}$ = annual change in carbon stocks in living biomass in land converted to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{GROWTH}}$ = annual increase in carbon stocks in living biomass due to growth in land converted to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{LOSS}}$ = annual decrease in carbon stocks in living biomass due to losses from harvesting, fuel wood gathering and disturbances in land converted to forest, tonnes C yr^{-1}

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[6] The default assumption in the *IPCC Guidelines* is that carbon does not accumulate in harvested wood products (HWP) pools, though countries may report on HWP pools if they can document that existing stocks of long term forest products are in fact increasing (Box 5 of the *IPCC Guidelines*). Future treatment of HWP is under discussion by the UNFCCC (i.e. the Conference of the Parties (COP) and COP7 decided that any changes to the treatment of HWP shall be in accordance with future decisions of the COP [Decision 11/CP.7 para 4]). With this background, discussions on methodological issues for HWP are placed in Appendix 3a.1

Tier 1 can be applied even when previous land uses are not known, which may be the case if areas are estimated using Approach 1 or 2 from Chapter 2. It uses default parameters that are provided in Annex 3A.1 (Biomass Default Tables).

Step 1: Annual Increase in Carbon Stocks in Living Biomass, $\Delta C_{LF_{GROWTH}}$. The method follows Equation 3.2.4, Section 3.2.1 Forest land Remaining Forest land, which refers to Category 5A "Changes in Forest and Other Woody Biomass Stocks" of the *IPCC Guidelines*. As growth rate of a forest strongly depends on management regime, a distinction is made between forests that are managed intensively (e.g. plantation forestry with intensive site preparation and fertilisation) and extensively (e.g. naturally regenerated forests with minimum human intervention). The calculations are made according to Equation 3.2.23:

EQUATION 3.2.23

ANNUAL INCREASE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{GROWTH}} = [\Sigma_k A_{INT\_MAN_k} \bullet G_{Total\ INT\_MAN_k} + \Sigma_m A_{EXT\_MAN_m} \bullet G_{Total\ EXT\_MAN_m}] \bullet CF$$

Where:

$\Delta C_{LF_{GROWTH}}$ = annual increase in carbon stocks in living biomass due to growth in land converted to forest land, tonnes C yr^{-1}

$A_{INT\_MAN_k}$ = area of land converted to intensively managed forest in condition *k* (including plantations), ha

$G_{Total\ INT\_MAN_k}$ = annual growth rate of biomass in intensively managed forest in condition *k* (including plantations), tonnes d.m. ha^{-1} yr^{-1}

$A_{EXT\_MAN_m}$ = area of land converted to extensively managed forest in condition *m*, ha

$G_{Total\ EXT\_MAN_m}$ = annual growth rate of biomass in extensively managed forest in condition *m*, tonnes dm ha^{-1} yr^{-1} (includes natural regeneration)

k, *m* = represent the different conditions in which intensively and extensively managed forests are growing

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

The annual increment in biomass of both intensively ($G_{Total\ INT\_MAN}$) and extensively $G_{Total\ EXT\_MAN}$) managed forests is calculated in accordance with Equation 3.2.5, Section 3.2.1 Forest land Remaining Forest land and with the use of default values provided in Tables 3A.1.5, 3A.1.6, 3A.1.7, 3A.1.8, 3A.1.9, and 3A.1.10 in Annex 3A.1. The values from tables should be chosen with regard to tree species composition and climatic region. Data for extensively managed forests should be taken from Table 3.A.1.5 and for intensively managed forests from Table 3A.1.6 or 3A.1.7.

Step 2: Annual Decrease in Carbon Stocks in Living Biomass Due to Losses, $\Delta C_{LF_{LOSS}}$. In case harvesting, fuel wood gathering and disturbances can be attributed to land converted to forest, annual losses in biomass should be estimated with the use of Equation 3.2.24 that repeats the *good practice* approach given in Equation 3.2.6, Section 3.2.1, Forest land Remaining Forest land:

EQUATION 3.2.24

ANNUAL DECREASE IN CARBON STOCKS IN LIVING BIOMASS DUE TO LOSSES IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{LOSS}} = L_{fellings} + L_{fuelwood} + L_{other\ losses}$$

Where:

$\Delta C_{LF_{LOSS}}$ = annual decrease in carbon stocks in living biomass due to losses in land converted to forest land, tonnes C yr^{-1}

$L_{fellings}$ = biomass loss due to harvest of industrial wood and saw logs in land converted to forest land, tonnes C yr^{-1}

$L_{fuelwood}$ = biomass loss due to fuelwood gathering in land converted to forest land, tonnes C yr^{-1}

$L_{other\ losses}$ = biomass loss due to fires and other disturbances in land converted to forest land, tonnes C yr^{-1}

The biomass loss due to harvest ($L_{fellings}$) is estimated with the use of Equation 3.2.7, Section 3.2.1, Forest land Remaining Forest land, and default basic wood density and biomass expansion factor values provided in Tables 3A.1.9 and 3A.1.10 of Annex 3A.1. The *good practice* approaches for estimating biomass losses due to fuel wood gathering ($L_{fuelwood}$), fires and other disturbances ($L_{disturbance}$) are also described in Section 3.2.1, Forest land Remaining Forest land. If no data on losses on this land category are available, all loss terms should be set to value 0, thus also $\Delta C_{LF_{LOSS}}$ then equals 0. It is *good practice* to ensure consistent reporting on losses of biomass between this category and Section 3.2.1 Forest land Remaining Forest land to prevent double accounting or omission of biomass loss.

Tier 2: The Tier 2 method is similar to Tier 1, but it uses more disaggregated approach and allows for more precise estimates of changes in carbon stocks in biomass. The net annual CO_2 removals in biomass are calculated as a sum of removals due to growth of biomass on the areas converted to forest, changes in biomass due to actual conversion (estimates the difference between initial biomass stocks on non-forest land before and after conversion to forest e.g. by artificial regeneration), and losses on areas converted to forest (Equation 3.2.25):

EQUATION 3.2.25
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS IN LAND CONVERTED TO FOREST LAND (TIER 2)

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

Where:

$\Delta C_{LF_{LB}}$ = annual change in carbon stocks in living biomass in land converted to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{GROWTH}}$ = annual increase in carbon stocks in living biomass due to growth in land converted to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{CONVERSION}}$ = annual change in carbon stocks in living biomass due to actual conversion to forest land, tonnes C yr^{-1}

$\Delta C_{LF_{LOSS}}$ = annual decrease in carbon stocks in living biomass due to losses from harvesting, fuel wood gathering and disturbances in land converted to forest land, tonnes C yr^{-1}

In addition to default values, the Tier-2 approach requires national data on: i) area converted to forest; ii) average annual increase per ha in merchantable volume on land converted to forests, obtained e.g. from forest inventories (no default values can be provided); iii) change of carbon in biomass when non-forest land becomes forest (e.g. by artificial regeneration) and iv) emissions due to loss of biomass on converted land. The approach may imply the knowledge of the land-use change matrix, and hence the distribution of previous land uses.

Step 1: Annual Increase in Carbon Stocks in Living Biomass, $\Delta C_{LF_{GROWTH}}$. The method follows the Tier 1 approach using Equation 3.2.23 above. The average annual increment in biomass of both intensively ($G_{Total\ INT\_MAN}$) and extensively ($G_{Total\ EXT\_MAN}$) managed forests is calculated in accordance with Tier 2 *good practice* approach, Section 3.2.1 Forest land Remaining Forest land and with the use of country-specific data on average annual increase per ha in merchantable volume on land converted to forests (obtained e.g. from forest inventories) and default basic wood density, biomass expansion factors and the ratio of belowground biomass to aboveground biomass provided in Tables 3A.1.7, 3A.1.8, 3A.1.9, 3A.1.10 in Annex 3A.1.

Step 2: Change in Carbon Stocks in Living Biomass Due to Conversion, $\Delta C_{LF_{CONVERSION}}$. The change of non-forest land to forest land (e.g. by artificial regeneration that includes clearing the vegetation on non-forest land) may cause change in the biomass stock in the conversion. The changes in carbon stocks in living biomass due to land-use change are calculated with the use of Equation 3.2.26:

EQUATION 3.2.26
CHANGE IN CARBON STOCKS IN LIVING BIOMASS
IN LAND ANNUALLY CONVERTED TO FOREST LAND

$$\Delta C_{LF_{CONVERSION}} = \sum_i [B_{AFTER_i} - B_{BEFORE_i}] \bullet \Delta A_{TO\_FOREST_i} \bullet CF$$

Where:

$\Delta C_{LF_{CONVERSION}}$ = change in carbon stocks in living biomass in land annually converted to forest land, tonnes C yr^{-1}

B_{BEFORE_i} = biomass stocks on land type i immediately before conversion, tonnes d.m. ha^{-1}

B_{AFTER_i} = biomass stocks that are on land immediately after conversion of land type i, tonnes d.m. ha^{-1} (in other words, the initial biomass stock after artificial or natural regeneration)

$\Delta A_{TO\_FOREST_i}$ = area of land-use i annually converted to forest land, ha yr^{-1}

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonnes d.m.)$^{-1}$

i = represent different types of land converted to forest

Note: The types of land should be stratified along biomass stocks before conversion

The $\Delta C_{LF_{CONVERSION}}$ can be expanded to take account of different carbon contents before transition. Tier 2 may apply calculations on subdivisions of land area (regions, ecosystems, site types etc.).

Step 3: Change in Carbon Stocks in Living Biomass Due to Losses, $\Delta C_{LF_{LOSS}}$. The annual losses in biomass are estimated using Equation 3.2.24. This equation repeats *good practice* approach given in Equation 3.2.6, Section 3.2.1, Forest land Remaining Forest land.

The biomass loss due to harvest ($L_{fellings}$) is estimated with the use of Equation 3.2.7, Section 3.2.1, Forest land Remaining Forest land. Tables 3A.1.9 and 3A.1.10 in Annex 3A.1 provide default data on basic wood density and biomass expansion factors. For Tier 2 and higher tiers, inventory experts are encouraged to develop country-specific wood density and BEF values for growing stock increment and harvests. The *good practice* approaches for estimating biomass losses due to fuel wood gathering ($L_{fuelwood}$), fires and other disturbances ($L_{disturbance}$) are also described in Section 3.2.1, Forest land Remaining Forest land. If no data on losses on this land category are available, all loss terms should be set to value 0, thus also $\Delta C_{LF_{LOSS}}$ then equals 0. It is *good practice* to ensure consistent reporting on losses of biomass between this category and Section 3.2.1 Forest land Remaining Forest land to avoid over- and underestimates due to double accounting or omissions.

Tier 3: The Tier 3 follows the same equations and steps as Tier 2, but should use substantial national methodology and solely country-specific data. Tier 3 should be used, when land conversion to forest represents a key category. In the inventory, Equations 3.2.25 and 3.2.26 are expanded on fine geographical scale and stratifications according to ecosystems, vegetation types, subdivision of biomass pools, and types of land before the conversions are made. Country-defined methodologies may be based on systematic forest inventory or use geo-referenced data, and/or models for accounting for changes in biomass. National activity data should have high resolution and be available on regular basis for all categories of converted lands and forest types established on them. The methodology should be described and documented as specified in Section 5.5.6 Documentation, Archiving and Reporting.

3.2.2.1.1.2 Choice of Emission/Removal Factors

INCREASE IN CARBON STOCKS IN LIVING BIOMASS, ΔC_{LF_G}

The calculations distinguish between two broad management practices: intensive (e.g. plantation forestry with intensive site preparation and fertilisation) and extensive (e.g. naturally regenerated forests with minimum human intervention) ones. These categories can also be refined according to national circumstances, for example based on stand origin e.g. natural or artificial regeneration.

Tier 1: The *IPCC Guidelines* provide default methodology only for aboveground biomass calculations. The present GPG report provides *good practice* approach to estimate for living biomass obtained as a sum of above- and belowground biomass pools (for pool description refer to Section 3.1 Introduction). The Tables 3A.1.5 and 3A.1.6 in Annex 3A.1 represent default average annual increment values in aboveground biomass of intensively and extensively managed forests (referred as plantations and naturally regenerated forests). The ratios of belowground to aboveground biomass (root-to-shoot ratio) in Table 3A.1.8 should be used to account for belowground biomass in living biomass estimations. Basic wood density (Table 3A.1.9) and biomass expansion factors (Table 3A.1.10) allow for calculation of biomass as stipulated in Section 3.2.1 Forest land Remaining Forest land.

Tier 2: It is *good practice* to determine wherever possible annual increment values, root-to-shoot ratios, basic wood density, and biomass expansion factors in accordance with national conditions and use them in calculations under Tier 2 approach. The possible stratifications go along tree species composition, management regime, stand age or volume, climatic region and soil type. Countries are encouraged to obtain specific biomass sequestration and expansion factors through research efforts. Further guidance is given in Section 3.2.1 Forest land Remaining Forest land.

Tier 3: The accounting for carbon removals in biomass should be implemented based on country-specific annual growth rates and carbon fraction in biomass from dedicated forest inventories and/or models. The inventory experts should ensure that the models and forest inventory data have been described in line with the sampling and other procedures outlined in Chapter 5, Cross-cutting Issues, of this report.

CHANGE IN BIOMASS STOCKS ON LAND BEFORE AND AFTER CONVERSION, $\Delta C_{LF_{CONVERSION}}$

It is *good practice* to use values of biomass stocks for pre-conversion land uses that are consistent with values used in calculations for other land categories. For example, if default carbon stock values were used to estimate changes in carbon stocks in grassland remaining grassland, then the same default values should be used to assess carbon stocks in grassland prior to their conversion to forest land.

Tier 1: The *IPCC Guidelines* do not include estimation of biomass changes in conversion process. $\Delta C_{LF_{CONVERSION}}$ is not included in Tier 1 calculations.

Tier 2: It is *good practice* to obtain and use wherever possible country-specific data on biomass stocks on land before and after conversion. The estimates should be consistent with those used in the calculations of carbon stock changes in grassland, cropland, wetlands, settlements and forest categories, and obtained from national agencies or sampling. A Tier 2 approach may use some combination of country-specific and default biomass stocks (given in Tables 3A.1.2 and 3A.1.3). For default values of biomass stocks for pre-conversion land uses refer to other land categories described in the present report.

Tier 3: Estimates and calculations should be performed based on country-specific survey and model data. Surveys should be based on the principles outlined in Section 5.3, and models and data documented in line with procedures outlined in Chapter 5, Cross-cutting Issues, of this report.

CHANGE IN CARBON STOCKS IN LIVING BIOMASS DUE TO LOSSES, ΔC_{LF_L}

Harvesting and natural disturbances such as windfall, fires and insect outbreaks can result in losses of carbon on lands converted to forests. It is *good practice* to report on them. Section 3.2.1 Forest land Remaining Forest land, of this report provides a *good practice* approach for estimating losses of carbon due to harvest and natural disturbance that is fully applicable and should be used for appropriate calculations under Section 3.2.2.1.1.1 above. If changes in C stocks are derived from repeated inventories, the losses from harvesting and disturbances will be covered without a need to report on them separately. It is *good practice* to ensure consistent reporting on losses of biomass between this category and Section 3.2.1 Forest land Remaining Forest land to prevent double accounting or omission part of biomass loss.

3.2.2.1.1.3 Choice of Activity Data

AREA OF LAND CONVERTED, A_{INT_MAN}, A_{EXT_MAN}, ΔA_{TO_FOREST}

All tiers require information on areas converted to forest land for a period of 20 years. After 20 years the areas are accounted for under Section 3.2.1 Forest land Remaining Forest land. Lands that undergo a conversion in prevailing use are covered here. Thus regeneration on existing forest land that was recently cleared as a result, for example, of harvesting or natural disturbance, should be accounted for in Section 3.2.1 Forest land Remaining Forest land because no change in land use is involved. The same data on areas should be used for Section 3.2.2.2 Change in Carbon Stocks in Dead Organic Matter, Section 3.2.2.3 Change in Carbon Stocks in Soils, and Section 3.2.2.4 Non-CO_2 Greenhouse Gas Emissions. The stratification in area estimation should take into consideration, if possible, the major soil types and biomass densities on land before and after conversion.

In order to be consistent with the reporting categories of the *IPCC Guidelines*, the areas of forests re-growing naturally on abandoned lands should be distinguished from other land conversion to forest. The inventory experts are encouraged to search for information on prior land use to make this distinction. When Approach 1 of Chapter 2 is used, additional data may be needed to distinguish between areas of natural and artificial regeneration.

Tier 1: Activity data can be obtained through national statistics, from forest services (which may have information on areas of different management practices), conservation agencies (especially for areas managed for natural regeneration), municipalities, survey and mapping agencies. Cross-checks should be made to ensure complete and consistent representation for avoiding omissions or double counting as specified in Chapter 2. If no country data are available, aggregate information can be obtained from international data sources (FAO, 1995; FAO, 2001; TBFRA, 2000).

Expert judgment can be used about whether the new forests are predominantly intensively or extensively managed. In that case A_{INT_MAN} and A_{EXT_MAN}, data can be obtained through multiplication of annual area changes in kha or by the period of conversion (the default period is 20 years). If the proportions of areas of intensively and extensively managed forests can be estimated, this information can be used for further partitioning the areas to obtain more accurate estimates.

Tier 2: The areas under different land categories subjected to conversion during a given year or over a period of years should be available. They come from national data sources and a land-use change matrix or its equivalent that covers all possible transitions to forest land. Country-defined national data sets should have a resolution sufficient to ensure appropriate representation of land areas in line with provisions of Chapter 2 of this report.

Tier 3: National activity data on conversion of land uses to forest through natural and artificial regeneration are available, possibly from different sources, notably national forest inventories, registers of land-use and land-use changes, and remote sensing, as described in Chapter 2 of this report. These data should give a full accounting of all land use transitions to forest land and disaggregate along climate, soil and vegetation types.

3.2.2.1.1.4 Uncertainty Assessment

Emission and removal factors: Non-zero default values of wood density and expansion factors may have a factor of two uncertainty associated with them. The major sources of uncertainty of default and country-specific data are associated with averaging highly variable primary numbers and further extrapolation of average values over broad areas. The use of regional and country-specific inventory data and models under Tiers 2 and 3 enables for significant reduction of uncertainties. Thus, the uncertainty of nationally determined values may be within ±30% (Zagreev *et al.*, 1992; Filipchuk *et al.*, 2000). The measures to reduce uncertainties include: increase of the number of representative sample plots and measurements over them; further stratification of estimates on the basis of similarity in growth, microclimate and other environmental characteristics; and development of local and regional parameters on the basis of comprehensive surveys and information exchange. If complex models are applied, the inventory experts should ensure their appropriate verification and documentation in accordance with Chapter 5 of this report.

Activity data: Uncertainties associated with activity data will depend on sources of information used nationally and the approaches used for land area identification described in Chapter 2 of this report. The combination of remote sensing data with ground-based surveys is the most cost-efficient method of measurements of areas of land-use change. It provides for uncertainties as low as ±10-15% and should be applied under higher tier methods. The major way to reduce uncertainty of area change estimates attributes to broad application of advanced land survey techniques on regional and local scale. However, its application may be limited by capacities of particular countries. To reduce both uncertainties of area estimates and costs of use of precise methods, regional remote sensing data centers could be established by several countries for sharing and common use of the information obtained for the purposes of sustainable land management.

3.2.2.2 CHANGE IN CARBON STOCKS IN DEAD ORGANIC MATTER

3.2.2.2.1 METHODOLOGICAL ISSUES

Methods to quantify emissions and removals of carbon in dead organic matter pools following conversion of land to forest land require estimates of the carbon stocks just prior to and just following conversion, and the estimates of the areas of lands converted during the period. Most other land uses will not have a dead wood or a litter pool, so that corresponding carbon pools prior to conversion can be taken as zero as a default assumption. Unmanaged forest, where converted to managed forest, could have significant carbon in these pools, as well as rangelands and wetlands, and also forest areas around settlements that may have been defined as settlements based on nearby use rather than land cover. The zero default should therefore be checked at Tiers 2 and 3. Conversion of non-forest to forest may occur so slowly that it may be difficult to distinguish when the conversion truly occurs; however, in these areas, if they were managed, the areas would probably be counted as managed forest depending on crown cover and other thresholds.

3.2.2.2.1.1 Choice of Method

Calculation procedure for change in carbon stock in dead wood

Conceptually once the carbon stock has been initiated to the value just prior to the conversion to forest (often zero by default, as discussed in the previous paragraph), annual changes for areas converting by plantations and on sites managed for natural regeneration, categorized by previous land use and forest type, can be estimated using Equation 3.2.27:

EQUATION 3.2.27
ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{DW}} = \{[A_{NatR} \bullet (B_{into_{NatR}} - B_{out_{NatR}})] + [A_{ArtR} \bullet (B_{into_{ArtR}} - B_{out_{ArtR}})]\} \bullet CF$$

where

$$B_{into_{NatR}} = B_{standing_{NatR}} \bullet M_{NatR} \text{ and } B_{into_{ArtR}} = B_{standing_{ArtR}} \bullet M_{ArtR}$$

Where:

$\Delta C_{LF_{DW}}$ = annual change in carbon stocks in dead wood in land converted to forest land, tonnes C yr^{-1}

A_{NatR} = area of land converted to forest land through natural regeneration, ha

A_{ArtR} = area of land converted to forest land through establishment of plantations, ha

B_{into} = average annual transfer of biomass into dead wood for forest area NatR or ArtR, tonnes d.m. ha^{-1} yr^{-1}

B_{out} = average annual transfer of biomass out of dead wood for forest area NatR or ArtR, tonnes d.m. ha^{-1} yr^{-1}

$B_{standing}$ = standing biomass stocks, tonnes d.m. ha^{-1}

M = mortality rate, i.e. proportion of $B_{standing}$ transferred annually into dead wood pool, dimensionless

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

Transfers into and out of a dead wood pool are difficult to measure and the stock change method described in Equation 3.2.28 may be easier to use than the previous equation if appropriate survey data are available, collected, for example, in conjunction with the National Forest Inventory:

EQUATION 3.2.28
ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{DW}} = [(B_{t_2} - B_{t_1}) / T] \bullet CF$$

Where:

$\Delta C_{LF_{DW}}$ = annual change in carbon stocks in dead wood in land converted to forest land, tonnes C ha^{-1} yr^{-1}

B_{t_2} = dead wood stock at time t_2, tonnes d.m. ha^{-1}

B_{t_1} = dead wood stock at time t_1 (the previous time), tonnes d.m. ha^{-1}

T = ($t_2 - t_1$) = time period between time of the second stock estimate and the first stock estimate, yr

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)$^{-1}$

The decision tree in Figure 3.1.2 (Section 3.1.6) provides assistance in the selection of the appropriate tier level for the implementation of estimation procedures. Dead wood carbon estimates often differ significantly by previous land use, forest type, and regeneration type. Theoretically, Equations 3.2.27 and 3.2.28 should give the same carbon estimates. In practical terms, data availability and desired accuracy determines choice of equation.

Tier 1 (Default): The *IPCC Guidelines*, consistent with reporting under Tier 1, assume no change in dead wood carbon in land converting to forest. This is consistent with Equation 3.2.27 on the assumption that annual transfers into the dead wood pool are the same as transfer out, and with Equation 3.2.28 if inventory of carbon stocks have been performed at different times.

Tier 2: Tier 2 uses Equation 3.2.27 when transfer rates into and out of the dead wood pool have been estimated using data from research plots sited nationally or in countries with similar conditions, and Equation 3.2.28 when carbon stocks are measured. For comparative purposes, new plots, where established, should be sited on the basis of the sampling principles set out in Section 5.3 with stratification by forest type and conversion regime.

Tier 3: Tier 3 methods can be used where countries have detailed inventories based on sample plots in their managed forests, or detailed models validated against representative litter accumulation data. The statistical design of the inventory (or for sample collection for model validation) should follow the principles set out in Section 5.3, which will facilitate unbiased results and provide information on associated uncertainties.

Calculation procedure for change in carbon stock in litter

The approach to estimating change of carbon in litter reflects expected differences in patterns and duration of changes in litter carbon for intensively managed plantations and naturally regenerating forests on lands converting to forest.

Conceptually once the carbon stock has been initialized to the value just prior to the conversion to forest (often zero by default, as just discussed), annual changes for areas converting by plantations and on sites managed for natural regeneration, categorized by previous land use and forest type, can be estimated using Equation 3.2.29:

EQUATION 3.2.29

ANNUAL CHANGE IN CARBON STOCKS IN LITTER IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{LT}} = [A_{NatR} \bullet \Delta C_{NatR}] + [A_{ArtR} \bullet \Delta C_{ArtR}]$$

Where:

$\Delta C_{LF_{LT}}$ = annual change in carbon stocks in litter in land converted to forest land, tonnes C yr^{-1}

A_{NatR} = area of land converted into forest land through natural regeneration, ha

A_{ArtR} = area of land converted into forest land through establishment of plantations, ha

ΔC_{NatR} = average annual change in carbon stocks in litter for forest area NatR, tonnes C ha^{-1} yr^{-1}

ΔC_{ArtR} = average annual change in carbon stocks in litter for forest area ArtR, tonnes C ha^{-1} yr^{-1}

Alternatively the stock change methods described in Equation 3.2.30 may be used if appropriate survey data are available:

EQUATION 3.2.30

ANNUAL CHANGE IN CARBON STOCKS IN LITTER IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{LT}} = A \bullet (C_{t_2} - C_{t_1}) / T$$

Where:

$\Delta C_{LF_{LT}}$ = annual change in carbon stocks in litter in land converted to forest land, tonnes C yr^{-1}

A = area of land converted to forest land, ha

C_{t_2} = litter carbon stock at time t_2, tonnes C ha^{-1}

C_{t_1} = litter carbon stock at time t_1 (the previous time), tonnes C ha^{-1}

T (= $t_2 - t_1$) = time period between time of the second stock estimate and the first stock estimate, yr

Methodological choice for estimating this pool is made using the general decision tree for land converted to forest land in Figure 3.1.2. Litter carbon estimates often differ significantly by previous land use, forest type, and regeneration type. Theoretically, Equations 3.2.29 and 3.2.30 should give the same carbon estimates. In practical terms, data availability and desired accuracy determines choice of equation.

Tier 1 (Default): The *IPCC Guidelines*, consistent with reporting under Tier 1, assume no change in carbon in the litter pools in lands converting to forest. This is consistent with Equation 3.2.29 on the assumption that annual transfers into the litter pool are the same as transfers out, and with Equation 3.2.30 when litter carbon stocks are assumed stable.

Tier 2: Tier 2 uses Equation 3.2.29 when transfer rates into and out of the litter pool have been estimated using data from research plots sited nationally or in countries with similar conditions, and Equation 3.2.30 when carbon stocks are measured. For comparative purposes, new plots, where established, should be sited on the basis of the sampling principles set out in Section 5.3 with stratification by forest type and conversion regime.

Tier 3: Tier 3 methods can be used where countries have detailed inventories based on sample plots in managed forests, or detailed models validated against representative litter accumulation data. The statistical design of the inventory (or for sample collection for model validation) should follow the principles set out in Section 5.3, which will facilitate unbiased results and provide information on associated uncertainties.

3.2.2.2.1.2 Choice of Emission/Removal Factors

DEAD WOOD

Tier 1: By default, consistent with reporting under Tier 1 in the *IPCC Guidelines*, it is assumed that the dead wood carbon stocks in non-forest lands converting to forests are stable. The net effect of emission and removal factors is therefore equal to zero.

Tier 2: Country-specific values for mortality rates related to standing biomass stocks are derived from scientific studies, or taken from nearby regions with similar forests and climate. If country-specific input factors are derived, corresponding loss factors for harvest and disturbance regimes could also be derived from country-specific data. If only one of the pair of country-specific input and output factors are available, then the assumption should be made that the other one of the pair is equal to the known factor. Default factors in Table 3.2.2 can be used for some forest categories if country or regional values are not available.

Tier 3: Countries develop their own methodologies and parameters for estimating changes in dead wood. Such approaches are likely to involve permanent inventory measurement programs, related to fine-resolution activity data, perhaps coupled modeling studies to capture the dynamics of all forest-related pools. Some countries have developed disturbance matrices which for each type of disturbance provide a carbon reallocation pattern among different pools (Kurz and Apps, 1992). Decay rates of dead wood may vary with the species of wood and microclimatic conditions, and site preparation procedures (e.g. controlled broadcast burning, or burning of piles). Default factors in Table 3.2.2 can be used as a check on country-specific factors.

LITTER

Tier 1 (Default): By default, it is assumed that the litter carbon stocks in non-forest lands converting to forests are stable. The net effect of emission and removal factors is therefore equal to zero. Countries experiencing significant changes in forest types, or disturbance or management regimes in their forests are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

Tier 2: Where these are available, it is *good practice* to use country level data for net litter accumulation rates for lands converting to forest by different forest types, in combination with default values in the final column of Table 3.2.1 if country or regional values are not available for some forest categories.

Tier 3: Countries develop their own methodologies and parameters for estimating changes in litter, using national level disaggregated litter carbon estimates for different forest types, disturbance or management regimes or both. These would be based on measurements from National forest inventories or other country-specific information, perhaps coupled with modeling studies to capture the dynamics of all forest-related pools. Updated default factors in Table 3.2.1 can be used as a check for country-specific factors.

3.2.2.2.1.3 Choice of Activity Data

Activity data should be consistent with the activity data used for estimating changes in living biomass on land areas undergoing conversion to forest. This can be obtained, consistent with the general principles set out in Chapter 2 and as described in Section 3.2.2.1.1.3, through national statistics, from forest services, conservation agencies, municipalities, survey and mapping agencies. Cross-checks should be made to ensure complete and consistent representation of annually converted lands in order to avoid possible omissions or double counting. Data should be disaggregated according to the general climatic categories and forest types in Table 3.2.1. Tier 3 inventories will require more comprehensive information on the establishment of new forests, with refined soil classes, climates, and spatial and temporal resolution. All changes having occurred over the T years selected as the transition period should be included with transitions longer ago than the past 20 years reported as a subdivision of forest remaining forest.

3.2.2.2.1.4 Uncertainty Assessment

Uncertainties for dead organic matter on land converted to forest land may be quite small in absolute terms in the first few years after conversion. Non-forest lands would have none to little dead organic matter. DOM can only occur once live vegetation is established, grows, and dies.

DEAD WOOD

The estimates for uncertainties of dead wood on land converted to forest land in the first few years after conversion may be close to zero percent. It is almost certain that there is zero dead wood on non-forest land prior to conversion to forest land. The longer the transition period chosen, the larger the uncertainties of dead wood on land converted to forest land. Uncertainties for dead wood on forest land remaining forest land are described in Section 3.2.1.2.1.4.

LITTER

The estimates for uncertainties of litter on land converted to forest land is very similar to estimates of uncertainties of litter on forest land remaining forest land, described in Section 3.2.1.2.1.4. Litter builds up relatively quickly. The shorter the transition period over which land stays in the category land converted to forest land, the less the litter uncertainty.

Table 3.2.5 provides the sources of uncertainty in estimating CO_2 emissions and removals from forest soils and dead organic matter pools, and indicates ways to reduce them.

Activity data: Uncertainties associated with activity data for dead organic matter should be consistent with the uncertainties for the activity data for estimating changes in living biomass on land area undergoing conversion to forest land, as described in Section 3.2.2.1.1.4.

3.2.2.3 CHANGE IN CARBON STOCKS IN SOILS

This section describes estimation procedures for carbon emissions and removals from the soils in land converted to forest land. Separate guidance is provided for two types of forest soil carbon pools: 1) the organic fraction of mineral forest soils, and 2) organic soils. The change in carbon stocks in soils in land converted to forest land ($\Delta C_{LF_{Soils}}$) is equal to the sum of changes in carbon stocks in the mineral soils ($\Delta C_{LF_{Mineral}}$) and organic soils ($\Delta C_{LF_{Organic}}$).

3.2.2.3.1 METHODOLOGICAL ISSUES

MINERAL SOILS

Studies of soil carbon dynamics upon changes from non-forest to forest indicate a wide range of trends, rates and timing. This variability is commonly explained by diffferences in experimental design and sampling procedures, varying land-use histories, climates and forest types (Paul *et al.*, 2002; Post & Kwon, 2000). Afforestation of improved grasslands has resulted in small decreases in mineral soil C in the upper soil horizon, which may or may not persist or be reversed over subsequent rotations (Paul *et al.*, 2002). Site characteristics were also found to be a strong determinant of C dynamics following afforestation on former pastures (Jackson *et al.*, 2002). Hence, there is no consistent pattern on the magnitude and direction of long-term soil C stock changes upon land-use changes from non-forest to managed forests (Post & Kwon 2000; Polglase *et al.*, 2000).

Generally, soil C is found to accumulate following afforestation on croplands (Polglase *et al.*, 2000). However, the rate of soil carbon accumulation can depend strongly on initial conditions, which relate to the intensity of the previous land-use and the remaining labile soil organic carbon prior to forest reestablishment (Post & Kwon, 2000). In spite of higher carbon inputs from litter, soil characteristics may also limit the contribution of SOC accumulation to total carbon sequestration in the ecosystem upon forest regrowth (Richter *et al.*, 1999). Depending upon soil sampling depths, the redistribution of organic carbon along the soil may lead to incorrect conclusions on the net changes in soil carbon stocks.

The proposed approach acknowledges the potential for sequestration or losses of SOC on lands converted to forest lands; it allows for the incorporation of the available scientific knowledge and data on the direction and rate of SOC changes in newly established forests.

Conceptually, the methodology is consistent with the one developed in Section 3.2.1.3.1.1 (Choice of Methods), in that it assumes a stable, spatially-averaged carbon content of mineral soils under given forest types, management practices and disturbance regimes. It is based on the following assumptions:

- Change from non-forest to forest land is potentially associated with changes in SOC, eventually reaching a stable end-point; and
- SOC sequestration/release during the transition to a new equilibrium SOC occurs in a linear fashion.

ORGANIC SOILS

Afforestation activities or forest regrowth on organic soils may alter the moisture regime through changes in interception of rainfall and evapotranspiration, and through increased organic matter inputs. These changes can modify the carbon dynamics and balance between the release of CO_2 and CH_4 to the atmosphere, leading to the expectation that land conversion to forest on drained organic soils – whether drained for this purpose, or previously drained – will be an anthropogenic source of CO_2. This is assumed not to be the case where conversion to forest occurs without drainage.

TABLE 3.2.5
SOURCES OF UNCERTAINTY IN ESTIMATING CO_2 EMISSION/REMOVAL FROM FOREST SOIL AND DOM POOLS

Sources of uncertainty	Characteristics	Treatment
Activity data		
Omission of managed forest areas	Not all managed forest areas is characterized by type, management practices and disturbance regimes; changes in forest types, practices or events are not documented	Document and monitor forest types, management practices and disturbances.
Omission of relevant changes in events or practices.	Omission of some LU changes, practices or disturbances believed to cause GHG emissions or removals	State and document; discuss likely effect on estimate validity
Mapping of spatial activity data (e.g. organic soils).	Areas or locations are not accurately mapped	Follow recommendations under Chapter 2 and standard GIS texts for the treatment of uncertainty associated with the manipulation of spatial data
Lack of proper stratification	Activity data are not stratified according to the variables which most contribute to the overall variability	Enhance the power of the sampling design through improved stratification
Use of default classification	National land-use classification incompatible with IPCC default	Design cross-walk
Parameters, emission/removal factors		
Use of default parameters or emission/removal factors	Default values do not represent national circumstances	Use default uncertainties. Prioritize improvements to reduce highest uncertainty first.
Sampling design	Stratification, sampling intensity, incompletely capture spatial variability	Quantify random uncertainty (see Chapter 5 or *GPG2000*)
Inconsistent sampling protocol	Horizon sampling, depth, replication, composite samples, handling of coarse fragments, bulk density measurements are not consistent	Improve and/or standardize sampling protocol; develop cross-walk between different protocols
Layer thickness	Only superficial (0-30 cm) soil samples were collected	Assume that 0-30 cm layer contains only 50% of forest soil C; estimate uncertainty accordingly
	Humus layer underneath boulders are not samples – overestimation of litter C stocks	Evaluate and adjust the sampling design at the plot level according to microspatial variability
	Inconsistent identification of soil horizons or reference depths	Vertical structure of soil profile should be assumed constant during repetitive sampling in forest sites without mechanical site preparation.
Bulk density (BD)	bulk density not measured at all sampling sites; inaccurate bulk density values, especially in compact or dense subsoils;	Use additional data from literature or databases to identify systematic error in BD and supplement missing data; request that representative measurements of BD be carried out
Coarse fragments	No assessment of the volume or mass of coarse fragments	Use additional data from literature or databases to identify systematic error in coarse fragment; calibrate and standardize the assessment of the coarse fragment content during sampling campaigns
Carbon concentration	Analytical methods for C analyses have changed	Avoid changing analytical methods if possible; develop correction factors from comparative lab studies, or used published ones
Scaling up of EF experimental values to large areas (e.g $EF_{Drainage}$)	Experimental values derived from site-specific studies are applied to large areas.	Follow guidance in Chapter 5 for scaling-up

3.2.2.3.1.1 Choice of Method

MINERAL SOILS

Equation 3.2.31 indicates that the soil carbon stock change for any inventory year is equal to the sum of carbon stock changes in new, intensively and extensively managed forests established for less than T years. The equation reflects expected differences in patterns and duration of changes in SOC for intensively managed forest and extensively managed forest.

EQUATION 3.2.31

ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS IN LAND CONVERTED TO FOREST LAND[1]

$$\Delta C_{LF_{Mineral}} = \Delta C_{LF_{Ext\ Forest}} + \Delta C_{LF_{Int\ Forest}}$$

Where,

$$\Delta C_{LF_{Ext\ Forest}} = [(SOC_{Ext\ Forest} - SOC_{Non\ Forest\ Land}) \bullet A_{Ext\ Forest}] \ / \ T_{Ext\ Forest}$$

$$\Delta C_{LF_{Int\ Forest}} = [(SOC_{Int\ Forest} - SOC_{Non\ Forest\ Land}) \bullet A_{Int\ Forest}] \ / \ T_{Int\ Forest}$$

and

$$SOC_{Int,\ Ext\ Forest} = SOC_{ref} \bullet f_{forest\ type} \bullet f_{man\ intensity} \bullet f_{dist\ regime}$$

Where:

$\Delta C_{LF_{Mineral}}$ = annual change in carbon stocks in mineral soils for inventory year, tonnes C yr^{-1}

$\Delta C_{LF_{Ext\ Forest}}$ = annual change in carbon stocks in mineral soils in land converted to extensively managed forest land, tonnes C yr^{-1}

$\Delta C_{LF_{Int\ Forest}}$ = annual change in carbon stocks in mineral soils in land converted to intensively managed forest land , tonnes C yr^{-1}

$SOC_{Ext\ Forest}$ = stable soil organic carbon stocks of the new, extensively managed forest, tonnes C ha^{-1}

$SOC_{Int\ Forest}$ = stable soil organic carbon stocks of the new, intensively managed forest, tonnes C ha^{-1}

$SOC_{Non\ Forest\ Land}$ = soil organic carbon stocks of the non-forest land prior to its conversion, tonnes C ha^{-1}

$A_{Ext\ Forest}$ = area of land converted to extensively managed forest, ha

$A_{Int\ Forest}$ = area of land converted to intensively managed forest, ha

$T_{Ext\ Forest}$ = duration of the transition from $SOC_{Non\ Forest\ Land}$ to $SOC_{Ext\ Forest}$, yr

$T_{Int\ Forest}$ = duration of the transition from $SOC_{Non\ Forest\ Land}$ to $SOC_{Int\ Forest}$, yr

SOC_{ref} = reference carbon stock, under native, unmanaged forest on a given soil, tonnes C ha^{-1}

$f_{forest\ type}$ = adjustment factor for a forest type different from the native forest vegetation, dimensionless

$f_{man\ intensity}$ = adjustment factor for the effect of management intensity, dimensionless

$f_{dist\ regime}$ = adjustment factor reflecting the effect on SOC of a disturbance regime different from the natural one, dimensionless

Note 1: These changes in carbon stocks should be reported annually for $T_{Ext\ Forest,}$ and $T_{Int\ Forest}$ years, respectively. For example, if a land is converted to intensively managed forest land and $T_{Int\ Forest} = 20$ years, then the annual changes in carbon stocks in mineral soils on the area $A_{Int\ Forest}$ as calculated with Equation 3.2.31 should be reported in the national inventory for 20 years following the conversion. The total change in carbon stocks in mineral soils is the sum of all types of conversions to forest land.

Where non-forest land is reverting to unmanaged, native forest vegetation:

$$f_{forest\ type} = f_{man\ intensity} = f_{dist\ regime} = 1, \text{ and}$$

$$SOC_{Int,\ Ext\ Forest} = SOC_{ref}$$

Annual changes in SOC occur as long as fewer than T years have elapsed since the non-forest to forest conversion.

The decision tree in Figure 3.1.2 (Section 3.1.6) provides basic guidance for tier selection in the estimation methodology.

Tier 1: Conversion of cropland and grassland to forest lands may optionally be considered at Tier 1, although the effects on soil carbon stock of conversions to forest land are not considered as part of the default methodology in the *IPCC Guidelines*[7]. There is no distinction between intensive and extensive management of new forests, hence $SOC_{Ext\ Forest} = SOC_{Int\ Forest} = SOC_{ref}$ and $T_{Ext\ Forest} = T_{Int\ Forest} = T_{Aff}$. The default equation is therefore simplified to:

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[7] Although losses of soil carbon from conversions from forest and grassland to other categories *are* considered.

EQUATION 3.2.32

ANNUAL CHANGE IN CARBON STOCKS IN MINERAL SOILS UPON AFFORESTATION[1]

$$\Delta C_{LF_{Mineral}} = [(SOC_{ref} - SOC_{Non\ Forest\ Land}) \bullet A_{Aff}] / T_{Aff}$$

Where:

$\Delta C_{LF_{Mineral}}$ = annual change in carbon stocks in mineral soils for inventory year, tonnes C yr^{-1}

SOC_{ref} = reference carbon stock, under native, unmanaged forest on a given soil, tonnes C ha^{-1}

$SOC_{Non\text{-}forest\ Land}$ = stable soil organic carbon on previous land use, either cropland or grassland , tonnes C ha^{-1}

A_{Aff} = the total afforested land derived from former cropland or grassland, ha

T_{Aff} = duration of the transition from $SOC_{Non\text{-}forest\ Land}$ to SOC_{ref}, yr

Note 1: These changes in carbon stocks should be reported annually for T_{Aff} years. For example, if a land is afforested and T_{Aff} = 20 years, then the annual changes in carbon stocks in mineral soils on the area A_{Aff} as calculated with Equation 3.2.32 should be reported in the national inventory for 20 years following the conversion.

Tier 1 calculations are very uncertain; countries for which land conversion to forests is a key category should report at Tier 2 or 3.

Tier 2: For Tier 2 calculations, the new forest types can initially be distinguished using two broad management categories: intensive management practices (e.g. plantation forestry with intensive site preparation and fertilisation) or extensive ones (natural forests with minimum intervention); these categories can also be refined according to national circumstances, for example based on stand origin such as natural or artificial regeneration. New forests established on lands whose former land-use was not cropland or grassland can be reported under this tier.

Tier 3: Tier 3 calculation procedures involve the development of a country-specific estimation methodology supported by disaggregated activity data and parameters, stratified by the ecological and anthropogenic factors which are nationally relevant. The methodology should be comprehensive, including all new managed forests, and all anthropogenic factors influencing the SOC balance of these lands. Section 3.2.1.3.1.1, Choice of Methods, provides a schematic outline of generic steps in the development of a domestic methodology.

ORGANIC SOILS

Where conversion to forest takes place on drained organic soils, countries should at Tiers 1 and 2 apply the estimation methodology described under the heading "Organic Soils" of Section 3.2.1.3.1.1 (Choice of Methods), using Equation 3.2.33 below, which is a modified version of Equation 3.2.15. Tier 3 methods should be used where extensive areas of drained organic soils have been converted to new forest lands. Emissions are assumed to continue for as long as the aerobic organic layer remains and the soil is considered to be an organic soil.

EQUATION 3.2.33

CO_2 EMISSIONS FROM DRAINED ORGANIC SOILS IN LAND CONVERTED TO FOREST LAND

$$\Delta C_{LF_{Organic}} = A_{Drained\ Aff} \bullet EF_{Drainage}$$

Where:

$\Delta C_{LF_{Organic}}$ = CO_2 emissions from drained organic forest soils in land converted to forest land, tonnes C yr^{-1}

$A_{Drained\ Aff}$ = area of drained organic soils in land converted to forest land, ha

$EF_{Drainage}$ = emission factor for CO_2 from drained organic forest soils, tonnes C ha^{-1} yr^{-1}

3.2.2.3.1.2 Choice of Emission/Removal Factors

MINERAL SOILS

The parameters to be estimated are SOC_{ref}, $SOC_{Ext\ Forest}$, $SOC_{Int\ Forest}$, $T_{Int\ Forest}$, $T_{Ext\ Forest}$, $SOC_{Non\ Forest\ Land}$, $f_{forest\ type}$, $f_{man\ intensity}$, and $f_{dist\ regime}$.

Tier 1: In Tier 1 calculations $f_{forest\ type} = f_{man\ intensity} = f_{dist\ regime} = 1$, hence the new forest SOC = SOC_{Ref}. Default SOC_{Ref} values under native vegetation for broad soil and climate categories are provided in Table 3.2.4.

Since only the conversion of cropland and grasslands are considered, values $SOC_{Non\ Forest\ Land}$ should be consistent with reported SOC values in croplands (see guidance in Section 3.3.1.2) or grasslands (see guidance in Section 3.4.1.2).

$T_{Nat\ Aff} = T_{Int\ Aff} = T_{Aff}$ the years for abandoned agricultural lands to recover to the native forest biomass under the native vegetation type and climate, which may be in the range 20 to 100 years, or longer for temperate and boreal ecosystems. These long term dynamics would need following in the forest remaining forest category once the land had been transferred from the conversion category.

Tier 2: In Tier 2 calculation procedures, countries provide their own values for SOC_{Ref}, $SOC_{Ext\ Forest}$, $SOC_{Int\ Forest}$, $T_{Int\ forest}$, $T_{Ext\ Forest}$, $SOC_{Non\ Forest\ Land}$, $f_{forest\ type}$, $f_{man\ intensity}$, and $f_{dist\ regime}$.

The default values for SOC_{Ref} should be replaced by data that better reflect national circumstances, based on relevant forest types, and natural disturbance regimes. Particular attention should be paid to SOC_{Ref} for which defaults should only be used as the stable, end-point SOC upon afforestation where there is documented evidence that the new forests are ecologically similar to native vegetation and not managed. Where forests have been established on areas with no historical forest, SOC_{Ref} may be derived from the most representative data available in the literature or from soil surveys of comparable forests and soil types.

National values for $SOC_{Ext\ Forest}$, $SOC_{Int\ Forest}$ and $f_{forest\ type}$, $f_{man\ intensity}$, and $f_{dist\ regime}$ should be consistent with the forest types, management practices and disturbance regimes used in estimation procedures of the SOC in forests remaining forests (Section 3.2.1.3.1.2, Choice of Emission/Removal Factors). Derivation of these parameters should be carried out according to the guidance provided in the corresponding text of Section 3.2.1.3.1.2.

Values of $SOC_{Non\ Forest\ Land}$ should be consistent with those reported in the other land categories.

The time period required to reach stable forest SOC values should be estimated, taking into account that rates of soil C sequestration are slower than those in aboveground biomass, that superficial changes in SOC may only present a partial picture of the vertical redistribution of carbon along the soil profile, that the transition may be shorter for new forests that are intensively managed than for extensively managed ones, and that, everything else being equal, in the long-term $SOC_{Int\ Forest}$ is likely to be lower than $SOC_{Ext\ Forest}$.

Linear C sequestration may be replaced by sigmoidal or equivalent representations, where data are available.

Tier 3: Countries develop their own methodologies and parameters for estimating changes in SOC associated with the creation of new forests. Such approaches will likely integrate rigorous, long-term monitoring programs, coupled with numerical and/or dynamic modelling studies, and will be consistent with the methods used to estimate emissions/removals for the SOC pools of forest land remaining forest land. Models should be selected based on their capacity to adequately represent the range of conditions and practices that occur over the area of interest, and their compatibility with available national data. Because of the complexity of these models, it may be difficult to quantify the uncertainty associated with the model outputs. The use of models should be supported by an independent validation of model assumptions, parameters, rules and outputs over the entire range of conditions and practices modelled.

ORGANIC SOILS

The emission factor to be estimated is $EF_{Drainage}$, for the emissions of CO_2 from drained organic soils converted to forest land [tonnes C ha^{-1} yr^{-1}], as discussed under emission factors for organic soils in Section 3.2.1.3.1.2. Default values are provided in Table 3.2.3.

3.2.2.3.1.3 Choice of Activity Data

MINERAL SOILS

Activity data under Tier 1 consist of all croplands and grasslands converted to forests, either deliberately or as a result of abandonment, estimated consistent with the guidance in Chapter 2. Typical conversion patterns show plantation establishment on marginal agricultural lands, on abandoned degraded agricultural lands in marginally productive areas, or on agricultural land and abandoned lands for other reasons.

Activity data under Tiers 2 and 3 consist of all lands converted to forest land, located according to the general climatic categories , and distinguished based on management intensity (extensive or intensive) and stand origin (natural or artificial forest establishment).

Under all tiers, new forests should remain in the conversion category for the duration of the transition period (default = 20 years), and subsequently included in forest land remaining forest land. Assessment of changes in forest SOC is greatly facilitated if the land-use change information can be used in conjunction with national soil and climate data, vegetation inventories, and other geophysical data, and long term soil carbon dynamics may need tracking in the forest land remaining forest land category after transferred at the end of the transition period.

Data sources will vary according to a country's land management systems, from individual contractors or companies, to regulation bodies and government agencies responsible for land use planning, inventory and management, and research institutions. Data formats include, among others, activity reports submitted regularly within incentive programs or as required by regulations, forest management inventories and remotely sensed imagery.

ORGANIC SOILS

The activity data consists of $A_{\text{Drained Aff}}$, the area of drained organic soils converted to new forests. When organic soils are drained for the purpose of afforesting the land, records will probably document the extent and location of drainage activities in preparation for forest establishment. This may not be the case for the conversion of previously drained soil, for which only the land conversion areas may be available. Additional surveys may be needed, using the advice in Chapter 2 taking into account any need to adjust areas ascribed to previous land uses to maintain consistent land area representation.

3.2.2.3.1.4 Uncertainty Assessment

Uncertainties in soil organic carbon data are basically the same in lands converted to forest land and in forest land remaining forest land (Section 3.2.1.3.1.4). An additional source of uncertainty is associated with the varying evidence on the effect of land conversion to forest land on the soil organic carbon (SOC): the direction and rate of changes in SOC depend on the initial soil conditions at the time of conversion, and the soil's potential for accumulating organic carbon. Unless there is contrary evidence, countries should assume a 30% uncertainty on soil initial conditions.

3.2.2.4 NON-CO_2 GREENHOUSE GAS EMISSIONS

Non-CO_2 gases from biomass burning are addressed in Section 3.2.1.4 (Greenhouse gas emissions from biomass burning).

In general, land conversion from cropland, grassland, settlements and other land to forest land tends not to alter sources and removals of non-CO_2 gases from soil as compared to the sources and removals occurring under the preceding (cropland, grassland, settlements, other land) or new land use (forest land). This assumption may not always hold true, for instance, if a grassland is ploughed for afforestation. However, insufficient data exist to provide a default methodology. N_2O emissions from management including fertilisation and drainage are addressed in Section 3.2.1.4 and Appendix 3a.2.

NITROUS OXIDE

Figure 3.1.2 provides the decision tree to select the respective tier for N_2O emissions from land converted to forest land. If data are available, the key category analysis should be performed separately for each land conversion type (cropland to forest land, grassland to forest land, wetlands to forest land, settlements to forest land, other land to forest land).

For **all Tiers** it is *good practice* to estimate N_2O emissions from direct application of nitrogen to lands in the conversion to forest land category using the same methods described in Section 3.2.1.4.1 for forest land remaining forest land, remembering to avoid double counting with forest land remaining forest land, or agriculture. If applications data cannot realistically be disaggregated below the forest land remaining forest land or even the agriculture level emissions should be lumped into the parent category, to avoid double counting. In addition the following points apply:

Tier 1: It is assumed that the conversion to forest land does not lead to soil carbon losses. Based on the argument set out in Section 3.3.2.3 (Non-CO_2 emissions from conversion to cropland), N_2O emissions from soil carbon mineralisation are also assumed to be zero. Lagged N_2O emissions from nitrogen application during the preceding land use and new land use (managed forest) are implicitly calculated in the inventory and do not need to be reported separately, avoiding double counting.

Tier 2: Countries with repeated soil carbon inventories are encouraged to check the assumption that the conversion to forest land does not lead to soil carbon losses. If soil carbon losses can be documented, e.g. from the afforestation of grassland, then N_2O emissions are reported using the same tiers and methodologies as for the conversion to cropland (Section 3.3.2.3, Non-CO_2 emissions from conversion to cropland). Lagged N_2O emissions from nitrogen application during the preceding land use are implicitly calculated in the inventory and do not need to be reported separately, avoiding double counting. At present, there is no adequate information to estimate the effect of carbon accumulation in soil on N_2O emissions.

Tier 3: For countries reporting N_2O emissions on a spatially explicit basis it is *good practice* to apply the same detailed models as for lands remaining forest land, taking account of the interactions identified for Tier 1 and Tier 2 above.

The conversion of organic soils to forest land releases N_2O in cases where the wetlands, especially organic soils, are drained. It is *good practice* to report N_2O emissions from drainage of organic soils for conversion to forest land with the same tiers and methodology as N_2O emissions from drained organic soils under forest land (Appendix 3a.2), assuring consistency.

3.2.3 Completeness

Completeness is a requirement for inventory Quality Assurance and (QA) and Quality Control (QC), as outlined in Chapter 5.5, and is defined, in the way set out in Chapter 1, by the coverage of the *IPCC Guidelines.*

This *Guidance* includes specific advice for all losses on managed forest areas (needed for the proper operation of the methodology), which, at higher tiers, extends to all pools, rather than just aboveground biomass. CO_2 and non-CO_2 emissions from fires and direct fertiliser application are included at all tiers and Appendix 3a.2 provides advice on nitrous oxide from drained organic soils. *Good practice guidance* on liming of forest soils is identical with the guidance in the *IPCC Guidelines* and has not been elaborated further, although more detailed methods are described in Chapter 4.

3.2.4 Developing a Consistent Time Series

It is *good practice* to develop a consistent time series of inventories of anthropogenic emissions and removals of GHGs in all LULUCF categories, using the guidance in Section 5.6 (Time series consistency and recalculations). Because activity data may only be available every few years, achieving time series consistency may require interpolation or extrapolation from longer time series or trends, possibly using information on changes in forest policies and incentive schemes where drivers are needed.

To estimate emissions and removals of GHGs, whether by Tier 1, 2 or 3, ideally the same protocol (sampling strategy, method, etc.) should be applied consistently to every year in the time series, at the same level of disaggregation, and, where country-specific data are used, it is *good practice* to use the same coefficients methods for equivalent calculations at all points in the time series.

However, as inventory capacity and information and data sources availability improve over time, new sources and sinks categories are included, or moving to higher tier, the methods and data used to calculate estimates can be updated and refined. In these circumstances, consistent recalculation of historical emissions and removals is a *good practice* (see Section 5.6.3, Recalculation of periodic data). In some cases, if some historical data are missing, then they may need to be estimated from other data sources.

Consistent accounting over time of land areas included in the soil C emissions/sinks inventory requires that activity data for all land-use categories be stratified by a common definition of climate and soil types. Thus areas subject to land-use change will be lost or double-counted due to accounting errors resulting from inconsistent definitions for climate and soil strata within other land-use categories. Consistent definition of each of the management systems included in the inventory is required.

The level of knowledge and detail of emission estimates for soils will also improve over time, necessitating recalculation of historic inventories to take account of new data and/or methods, so that activity data are stratified by common definitions of new forest types, management practices and disturbance regimes.

Often, changes in forest soils cannot be detected at time scale finer than a decade; it will be necessary to interpolate between measurements in order to obtain annual estimates of emissions and removals.

Changes in forest types, practices and disturbances need to be tracked for long time periods determined for example by soil carbon dynamics or forest rotation periods where these are specifically tracked in detailed model calculations. Difficulties may arise from lack of historical data on these activities or events. Historical data (including for non-CO_2 emissions drained and rewetted areas) will inevitably be of coarser resolution than recent data; some may have to be reconstructed, based on expert knowledge, which should be documented as set out in Chapter 5.

3.2.5 Reporting and Documentation

The categories described in Section 3.2 can be reported using the reporting tables in Annex 3A.2. The general requirements for reporting and documentation are set out in Chapter 5 of this report and in general it is a *good practice* to archive and document all data and information (such as figures, statistics, sources of assumptions, modeling approaches, uncertainty analyses validation studies, inventory methods, research experiments, measurements arising from field site studies, associated protocols, and other basis of basic data) applied to produce the national emissions/removals inventory. Elaborations on pool definition should be reported, and definitions relevant to determining the extent of the managed land included in the inventory, together with evidence that these definitions have been applied consistently over time.

Documentation is also needed for demonstrating completeness, consistency of time series data and methods for interpolating between samples and methods for interpolating between samples and years, and for recalculating, and avoidance of double counting as well as for performing QA/QC.

As Parties decide to progress through higher tier levels, whose calculation methods and data are not described in the *IPCC Guidelines* or characterised by more disaggregated approaches, additional documentation is required to support the use of more advanced and accurate methodologies, country-defined parameters, and high resolution maps and data sets. However, at all tier levels, explanation is needed for decisions regarding choice of methodology, coefficients, and activity data. The aim is to facilitate reconstruction of the estimates by independent third parties, but it may prove impractical to include all documentation necessary in the national inventory report. The inventory should therefore include summaries of approaches and methods used, and references to source of data such that the reported emissions estimates are transparent and steps adopted in their calculation may be retraced.

Documentation is particularly important where the approach, calculation methods and data are not described in the *IPCC Guidelines*, as in higher tier or more disaggregated approaches. In addition, it is a *good practice* to provide documentation on:

Emission factors: Sources of the emission factors that were used (specific IPCC default values or otherwise) have to be quoted. If country- or region-specific emission factors were used, and if new methods (other than the default IPCC methods) were used, the scientific basis of these emission factors and methods should be completely described and documented. This includes defining the input parameters and describing the process by which these emission factors and methods are derived, as well as describing sources and magnitudes of uncertainties. Inventory agencies using country-specific emission factors should provide information of the basis for the selection of a different factor, describe how it was derived, compare it to other published emission factors, explain any significant differences, and attempt to place bounds on the uncertainty.

Activity data: Sources of all activity data, such as areas, soil types and characteristics and vegetation covers, used in the calculations should be provided (i.e. complete citations for the statistical databases from which data were drawn). Reference to the metadata for the databases are useful, including information on dates and frequency of data collection, sampling procedures, analytical procedures used to obtain soil characteristics and minimum detectable change in organic carbon, and estimates of accuracy and precision. When activity data were not obtained directly from databases, the information and assumptions that were used to derive the activity data should be provided, as well as estimates of the uncertainty associated to the derived activity data. This applies in particular when scaling up procedures were used to derive large-scale estimates; in these cases the statistical procedures should be described along with the associated uncertainty.

Results of model simulations: If inventory agencies used data output from models in their estimation procedures, the rationale for model selection and use should be provided. It is a *good practice* to provide complete citations of peer-reviewed publications in which the model is described, and modelling results are interpreted and validated. Detailed information should be provided to enable reviewers to assess the model's validity, including the general modelling approach, key model assumptions, input and output data, parameter values and parameterisation procedures, confidence intervals of model outputs, and the outcome of any sensitivity analysis conducted on the output.

Analysis of emissions: Significant fluctuations in emissions between years should be explained. A distinction should be made between changes in activity levels and changes in emission coefficients from year to year, and the reasons for these changes documented. If different emission factors are used for different years, the reasons for this should be explained and documented.

Non-CO_2 greenhouse gases: the requirements on reporting follow three same principles as for CO_2, but particular attention needs to be given to methods for avoidance of omission or double counting with respect to agriculture and between forest land remaining forest land, and transitions to forest land. Clarity is also needed on coverage, between emissions estimated using the guidance in this chapter and any use made of the guidance in the Annex 3A.2 (Reporting Tables and Worksheets). In view of the uncertainties clarity in methods and reporting may help advance scientific knowledge as well as serve the purposes of inventory review.

3.2.6 Inventory Quality Assurance/Quality Control (QA/QC)

The characteristics of the LULUCF sector mean that estimates of emissions and removals of GHGs to be reported by national inventories can have different level of precision, accuracy and levels of bias. Moreover, the estimates are influenced by the quality and consistency of data and information available in a country, as well as gaps in knowledge; in addition, depending on the tier level used by a Party, figures can be affected by different sources of errors, such as sampling errors, assessment errors, classification errors in remote sensing imagery, model errors, that can propagate to the total estimation.

It is *good practice* to execute quality control checks through Quality Assurance (QA) and Quality Control (QC) procedures, and expert review of the emission estimates. Additional quality control checks as outlined in Tier 2 procedures in Chapter 8, QA/QC, of *GPG2000* and in Chapter 5.5 of this report, and quality assurance procedures may also be applicable, particularly if higher Tier methods are used to estimate emissions. It is *good practice* to supplement the general QA/QC related to data processing, handling, and reporting and documenting, with source-specific category procedures discussed below.

Agencies which collect data are responsible for reviewing the data collection methods, checking the data to ensure that they are collected and aggregated or disaggregated correctly, and cross-checking the data with other data sources and with previous years to ensure that the data are realistic, complete and consistent over time. The basis for the estimates, whether statistical surveys or ´desk estimates´, must be reviewed and described as part of the QC process. Documentation is a crucial component of the review process because it enables reviewers to identify inaccuracy, gaps and suggest improvements. Documentation and transparency in reporting is most important for highly uncertain source categories and to give reasons for divergences between country-specific factors and default or factors used by other countries. Countries with similar (ecological) conditions are encouraged to collaborate in the refinements of methods, emissions factors and uncertainty assessment.

ACTIVITY DATA CHECK

The inventory agency should, where possible, check data comprising of all managed land areas, using independent sources and compare them. Any differences in area records should be documented for the purposes of review. Activity data area totals should be summed across all land-use categories to insure that total area involved in the inventory and its stratification across climate and soil types, remains constant over time. This ensures that land areas are neither ‘created’ nor ‘lost’ over time, which would result in major errors in the inventory. When using country-specific data (such as data on standing biomass and biomass growth rates, carbon fraction in aboveground biomass and biomass expansion factors, synthetic fertiliser consumption and synthetic fertiliser consumption estimates) the inventory agency should compare them to the IPCC default values or internationally well-established values such as those provided by the FAO and the International Fertilizer Industry Association (IFA), and note the differences.

The country-specific parameters should be of high quality, preferably peer-reviewed experimental data, adequately described and documented. The agencies performing the inventory are encouraged to ensure that *good practice* methods have been used and the results have been peer-reviewed. Assessments on test areas can be used to validate the reliability of figures reported.

The inventory agency should make sure that QA/QC in the Agriculture source category has been implemented and that nitrogen excretion, volatile losses and application rates to forest are consistent with the Agriculture source category and overall consumption of fertilisers and organic wastes, avoiding double counting.

The inventory agency should make sure that the entire area of drained forest peatlands is considered, not only the recent drainage in the reporting year, and that repeated drainage of a given area is not counted as new area.

INTERNAL AND EXTERNAL REVIEW

The review processes as set out in Chapter 5 should be undertaken by experts preferably not directly involved in the inventory development. The inventory agency should utilize experts in GHG removals and emissions in LULUCF to conduct expert peer-review of the methods and data used. Given the complexity and uniqueness of the parameters used in calculating country-specific factors for some categories, selected specialists in the field should be involved in such reviews. If soil factors are based on direct measurements, the inventory agency should review the measurements to ensure that they are representative of the actual range of environmental and soil management conditions, and inter-annual climatic variability, and were developed according to recognised standards. The QA/QC protocol in effect at the sites should also be reviewed and the resulting estimates compared between sites and with default-based estimates.