CHAPTER 5
LAND-USE CHANGE & FORESTRY

5. LAND-USE CHANGE & FORESTRY

5.1 Overview

This chapter summarises methods for calculating greenhouse gas (GHG) emissions from human activities which:

1. change the way land is used (e.g., clearing of forests for agricultural use, including open burning of cleared biomass), or

2. affect the amount of biomass in existing biomass stocks (e.g., forests, village trees, woody savannas, etc.).

The biosphere is a strong determinant of the chemical composition of the atmosphere. This has been true since the existence of the biosphere, and hence well before the presence of humans. A rich variety of carbon, nitrogen, and sulphur gases are emitted and absorbed by the biosphere. There is, however, strong evidence that the expanding human use and alteration of the biosphere for food, fuel and fibre is contributing to increasing atmospheric concentrations of GHGs. The dominant gas of concern in this source category is carbon dioxide (CO_2), and much of the methodology discussion in this chapter is specific to CO_2. Other important direct GHGs, including methane (CH_4) and nitrous oxide (N_2O), and indirect GHGs,[1] including carbon monoxide (CO), oxides of nitrogen (NO_x, i.e., NO and NO_2), and non-methane volatile organic compounds (NMVOCs) are also produced from land-use change and forest management activities, particularly where burning is involved. Non-methane volatile organic compounds are emitted in significant quantities from biomass burning. These emissions could be estimated using the same approach provided for other non-CO_2 gases. However, the detailed methods and default information have not yet been developed and are not included in this version of the *Guidelines.* This is an area to be considered in future improvements to the *Guidelines*.

Estimates of CO_2 emissions due to land-use change vary considerably because humans interact with the land in a myriad of ways. Estimates vary due to uncertainties in annual forest clearing rates, the fate of the land that is cleared, the amounts of biomass (and hence carbon) contained in different ecosystems, the modes by which CO_2 is released (e.g., burning or decay) and the carbon released when soils are disturbed. The 1995 IPCC Scientific Assessment (IPCC, 1996) estimated the average annual flux due to tropical deforestation for the decade 1980-1989 to be 1.6±1.0 Pg C as CO_2 (CO_2-C). Carbon sequestration by tropical tree plantations was not explicitly included in these estimates but is thought to be relatively small: in 1980 these plantations were estimated to absorb only 0.03-0.11 Pg CO_2-C (Brown et al. 1986). Recent analyses have suggested that growth of existing forests in temperate and boreal regions may be a significant carbon sink, potentially as much as 0.7 Pg C annually. Analysts have suggested a number of complementary factors which could be causing these sinks, including regrowth of historically cleared forests, CO_2 fertilisation, and nitrogen fertilisation due to atmospheric deposition (e.g., IPCC, 1995; Kokorin and Nazarov, 1995a; Tans et al., 1990; Kauppi et al., 1992; and Dixon et al., 1994). Based upon the latest estimates of CO_2 sources, sinks and

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[1] "Indirect" greenhouse gases here refers to gases which, although not important GHGs in their own right, can influence the concentration of some GHGs, tropospheric ozone in particular.

atmospheric storage, the IPCC estimates a remaining terrestrial sink of 0.9 ± 0.5 Pg C/year to 1.4 ± 1.5 Pg C/year (Schimel et al., 1995; and Brown et al., 1996). This apparent imbalance in the carbon budget, which was previously referred to as a "missing sink," is believed to be due to CO_2 fertilisation, N fertilisation, climate change (e.g., temperature increase), more extensive regrowth or tree planting programmes in the tropics, and possibly other factors.[2] The precise mix and relative contribution of these processes to the remaining terrestrial sink is still a subject of research and debate; and this terrestrial sink will not necessarily remain the same size or even the same sign under conditions of climate change.

Emissions of non-CO_2 trace gases (CH_4, CO, N_2O, and NO_x) due to biomass burning are generally produced immediately and are considered as net emissions. NMVOC are not treated here. Gross emissions of CO_2 due to reductions in forest area may or may not be balanced by uptake of CO_2 and may occur over immediate or delayed time frames.[3] Similarly, increases in forest area or in the biomass density of existing forests will result in CO_2 uptake at varying rates and over delayed time frames. Only about 50-60 per cent of the carbon estimated to have been released in 1980 from forest conversion was a result of the conversion and subsequent biomass burning in that year. The remainder was a release due to oxidation (i.e., inherited emissions) of biomass harvested in previous years (Houghton, 1991). Other land-use changes, such as land flooding, result in continuous GHG emissions possibly for as long as the land remains in its altered state.

5.1.1 Background - Biomass Stocks and Carbon Fluxes

Vegetation withdraws CO_2 from the atmosphere through the process of photosynthesis. Carbon dioxide is returned to the atmosphere by the respiration of the vegetation (autotrophic) and the decay of organic matter in soils and litter (heterotrophic respiration). The gross fluxes are large; roughly a seventh of the total atmospheric CO_2 passes into vegetation each year (in the order of 100 Pg CO_2-C per year), and in the absence of significant human disturbance, this large flux of CO_2 from the atmosphere to the terrestrial biosphere is thought to be balanced by the return respiration fluxes.

Land-use change and the use of forests directly alters these fluxes, and their balance, and consequently the amount of carbon stored in living vegetation, litter, and soils. For example, forest clearing for agriculture by burning greatly increases the return flux of CO_2 and decreases for a while the photosynthetic flux. Burning is, after all, simply a rapid form of oxidation or decay. Subsequently, the CO_2 flux of the cleared area will reach a new steady state: the photosynthesis associated with agricultural production being balanced by the respiration of vegetation, the decay of on-site organic material, and the

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[2] For recent analyses of the effects of changing CO_2 concentrations and climate variables on terrestrial sinks, see, Cramer and Solomon, 1993; Smith and Shugart, 1993; Kokorin and Nazarov, 1995b; Mellilo et al., 1993; and Alcamo et al., 1994. For analysis of the possible effects of N fertilisation from atmospheric deposition, see Gifford, 1994, Rastetter et al., 1992 and Comins and McMurtrie, 1993. It is also possible that atmospheric deposition of air pollutants can damage forests, as discussed in Denniston, 1993, which would reduce the amount of carbon stored in forests. However, it is uncertain whether or not this is a significant effect at global or national scales.

[3] Delayed releases of non-CO_2 trace gases are an important research issue. These releases may be important , but are currently too uncertain to be included in calculations.

oxidation of the agricultural product when it is consumed, perhaps off site. However, the total amount of carbon stored in the terrestrial system will have been reduced because a forest contains more carbon than does a field of annual crops or pasture, and the removed carbon (i.e., the forest) was not put into long term storage pools. Consequently there is a net flux of CO_2 from the land (vegetation and soil) to the atmosphere. A natural first order assumption is that the net reduction in carbon stocks is equal to the *net* CO_2 flux from the cleared area.

Forest harvest does not necessarily result in a net flux to the atmosphere. It can produce a complex pattern of net fluxes that change direction over time. For instance, suppose that a forest is harvested, producing wood products and leaving some slash and debris. Initially, the CO_2 flux from the wood products that decay rapidly, plus the increased respiration flux of CO_2 associated with the oxidation of the slash, could exceed the flux from the atmosphere due to photosynthesis and the resulting carbon storage in the regrowing forest. Consequently, there is a net flux of CO_2 from the forest, forest floor and soil to the atmosphere. This would also be reflected in the carbon accounting: the amount of carbon in the original living vegetation, the litter, and the soils would be greater than the amount of carbon in the young regrowing forests, litter, soils and forest products pool. However, if some of the forest products are very long-lived, and if the forest regrows to its original level, then the integrated net flux must have been from the atmosphere to the terrestrial biosphere since the resulting total terrestrial carbon stocks (vegetation, litter, soils, and wood products) would be greater than before the forest harvest.

This characteristic, that changes in landuse today affect both present and future CO_2 fluxes associated with that specific landuse, is one feature of CO_2 emissions analysis that distinguishes landuse from fossil fuel consumption. Consequently, when one considers the issue of CO_2 flux associated with landuse today or in any base year, one must consider past land-use activities and their effects upon current fluxes of CO_2. Box 1 provides some illustrative numerical examples of carbon fluxes associated with land-use change over a series of years.

5.1.2 The Proposed Approach

The fundamental basis for the methodology rests upon two linked themes: i) the flux of CO_2 to or from the atmosphere is assumed to be equal to changes in carbon stocks in existing biomass and soils, and ii) changes in carbon stocks can be estimated by first establishing rates of change in land use and the practice used to bring about the change (e.g., burning, clear-cutting, selective cut, etc.). Simple assumptions are then applied about their impact on carbon stocks and the biological response to a given landuse. As noted above, there are large uncertainties in all current methods for estimating fluxes of CO_2 from forestry and land-use change. *Direct* measurements of changes in carbon stocks are extremely difficult since one must confront the difficulty of determining small differences in large numbers as well as the inherent heterogeneity of terrestrial systems. A more practical first order approach in many countries is to make simple assumptions about the effects of land-use change on carbon stocks and the subsequent biological response to the land-use change, and to use these assumptions to calculate carbon stock changes and hence the CO_2 flux. This observation is at the heart of the proposed approach.

Rates of change of land use are difficult to establish, although there are a variety of data on which to base land-use change estimates. The Technical Appendix to this chapter reviews sources of data on rates of tropical deforestation, the land-use change which currently makes the largest contribution to CO_2 flux. Finally, the assumptions regarding the response of vegetation and soils to different land uses and land-use change can be expressed in simple terms which can be altered for specific conditions in different countries or regions.

The methodology is designed to be comprehensive, i.e., to cover all of the main land-use change and forestry activities; and to be feasible to implement by all participating countries. It can be implemented at several different levels of complexity and geographic scales, depending on the needs and capabilities of national experts in different countries.

1. A simple, first order approach can be based on very aggregate default data and assumptions, derived from the technical literature, and provided throughout the text. Methods are presented in the context of national level aggregate calculations for a limited set of subcategories which can be supported by these default values. It is important to note that many of the default data provided in the land-use change and forestry chapter are highly uncertain. Many of the important values needed for the calculations are not well established or are highly variable from region to region, or within very small subregions within a given country. In many cases in which values are particularly uncertain (e.g., the fraction of cleared biomass burned on site), these weaknesses are discussed in the text. Where global average values are highly uncertain, they can be used for first order calculations or for comparison, but probably do not provide a basis for a credible final inventory. National experts in forestry and related fields should be consulted to determine the most appropriate values for use in national inventories.

2. A more accurate level can be achieved simply by substituting country-specific values for general defaults provided in the methodology. If appropriate and possible, locally available data can be used to carry out calculations at a more detailed geographic scale and/or subcategory level. Alternative levels of detail are discussed more fully in the next section. National experts are strongly encouraged to substitute more appropriate (i.e., country- or region-specific) and more detailed input data wherever they are available.

3. Forest inventory data can also be used with this methodology. It is important to note that some countries with highly developed forestry industries do in fact keep track of existing commercial forests through periodic detailed inventories. In these countries it is generally the ongoing management of existing forests rather than land-use changes which has the greatest impact on the exchange of GHG between the land and atmosphere. National experts who have very detailed, inventory based data, can re-format and analyse these data to derive equivalent average responses (e.g., annual biomass growth rates by ecosystem type) which can be aggregated up to categories matching the simple approach outlined here. This procedure is discussed in more detail in the *changes in forest and other woody biomass stocks* section below.

The intent is to provide a calculation and reporting framework which can accommodate users with vastly different levels of available data, yet allow them all to present the results on a comparable basis.

BOX 1
ILLUSTRATIVE CALCULATIONS OF CARBON FLUXES

Consider the example of forest clearing for agriculture which results in a net flux to the atmosphere. For descriptive purposes we consider the following assumptions:

1) a 20 year time frame (e.g., 1970 to 1990);
2) one hectare is cleared each year (so that over the 20 year period, 20 hectares are cleared);
3) cleared land is used as pasture, which is established the year following the clearing;
4) after three years, cleared land is abandoned and it regrows linearly at 10tC/ha per year to 75 per cent its original biomass only in 15 years;
5) all of the vegetation is completely burned at the time of clearing and there are essentially no changes in soil or litter pools; and
6) there are 200 tonnes of carbon per hectare in the forest biomass and 5 tonnes carbon per hectare in the pasture.

In the first year, there is a 200 tonne net flux of carbon as CO_2 to the atmosphere. In the second there is a 195 tonne net flux; the clearing of the second hectare is partially balanced by the establishment of the first pasture. In the third, there is a net flux again of 195; the clearing of the third hectare is again partially balanced by the establishment of the second pasture; however, the first pasture is now again in a steady state (as a pasture). The fourth year the pattern is again the same, but in the fifth year the net annual flux drops to 185 as the first pasture is now abandoned and begins to recover to a secondary forest. In the sixth year, the flux drops to 175 as two hectares are recovering to a secondary forest. In this example, in 1989 one hectare would be converted to pasture (200 tonne flux of carbon to the atmosphere), one hectare would have become a pasture (5 tonne flux to the terrestrial biosphere), two hectares would be in steady state as pasture, and 15 hectares would be recovering to secondary forest with one hectare in its final year of recovery (150 tonne flux to the terrestrial biosphere). The gross flux of carbon from land clearing in 1989 would still be 200 tonnes to the atmosphere, but the net flux to the atmosphere in 1989 associated with land clearing would be 45 tonnes of carbon as CO_2. The 1990 flux would be the same since now the original one hectare of pasture would have reached a new steady state as a secondary forest.

Many variations on this example can be devised: e.g., conversion of some vegetation to charcoal, varying deforestation and regrowth rates. For instance, if the land clearing rates declined over the time period, the 1990 net flux could easily be from the atmosphere to the biosphere even though the net integrated flux over the time period was to the atmosphere.

There are other complexities such as the variety of land-use practices, different assumptions about biomass densities, recovery rates, the dynamics of the associated litter and soil pools, and so forth. However, the net flux to or from a particular site will always be reflected in the change of carbon stocks on site and/or in the products pools associated with the site. Thus, a methodology that determines carbon stock changes also provides estimates of the net fluxes of CO_2.

5.1.3 Priority Categories

In estimating the effects of landuse and land-use changes on the emissions of GHGs, it is reasonable to stage the calculation methods so that the most important components can be addressed first. Complexities and subtleties of the relationship of forestry and land-use change to fluxes of CO_2 and other gases can be incorporated in a consistent manner into subsequent calculations as knowledge advances and data improve. The methodology presented in this chapter focuses initially on a simple, practical and fair procedure for determining the biomass-derived CO_2 flux directly attributed to forest management and land-use change activities. This procedure must also account for the influence of inherited "emissions" or past land-use changes upon the contemporary CO_2 flux,[4] as well as trace gas emissions from biomass burning where this occurs in conjunction with land-use change.[5]

The general forest and grassland ecosystem categories are listed in Box 2. Detailed description of tropical forest types and regional forest formations are presented in Table 5-1.

On a global scale, the most important land-use changes that result in CO_2 emissions and removals are:

- **changes in forest and other woody biomass stocks -** the most important effects of human interactions with existing forests are considered in a single broad category, which includes commercial management, harvest of industrial roundwood (logs) and fuelwood, production and use of wood commodities, and establishment and operation of forest plantations as well as planting of trees in urban, village and other non-forest locations;[6]
- **forest and grassland conversion -** the conversion of forests and grasslands to pasture, cropland, or other managed uses can significantly change carbon stored in vegetation and soil;[7]
- **abandonment of croplands, pastures, plantation forests, or other managed lands** which regrow into their prior natural grassland or forest conditions.
- **changes in soil carbon.**

The method also addresses the immediate release of non-CO_2 trace gases (CH_4, CO, N_2O and NO_x) from the open burning of biomass from forest clearing.

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[4] Similarly, current land-use changes will affect future fluxes of CO_2.

[5] Burning of biomass residues can occur in other situations which are not land-use change, e.g., in the use of forests or other biomass stocks as a part of the ongoing management of these stocks without changing the land use. This should be treated in the same way as burning of cleared forests for calculation of non-CO_2 GHG from burning.

[6] Changes in forest and other woody biomass stocks are accounted for in each Inventory Year.

[7] Conversion of forests is also referred to as "deforestation" and it is frequently accompanied by burning.

BOX 2
FOREST AND GRASSLAND CATEGORIES

Ecosystem categories have been established based on conventions common in the literature. For the tropics, the categories are based mainly on the FAO system (FAO 1993a) to be consistent with the tables of default values provided, and used in the simple calculations presented in the Workbook. National experts are free, indeed encouraged, to use more detailed characterisations of ecosystems in their countries if the data are available and differences are important for carbon calculations. If more detailed categories are used, however, it is necessary to aggregate these up to match the broad specified categories in order to ensure consistency and comparability with national data across all participating countries. The categories are presented as follows:

Ecosystem Types

Tropical Ecosystems

Forests	Wet
	Moist with short dry season
	Moist with long dry season
	Dry
	Montane moist
	Montane dry
Grasslands/Shrublands	Mainly herbaceous and shrub savannas/ grasslands

Temperate Ecosystems

Forests	Broadleaf
	Coniferous
Grasslands	

Boreal Ecosystems

Forests	Coniferous
	Mixed broadleaf-coniferous
	Forest-tundra
Grasslands/Tundra	

Within each ecosystem category, subdivisions are recommended where data are available. For example, tropical forests are defined as ecosystems with a minimum of 10% crown cover of trees and/or bamboos, generally associated with wild flora, fauna and natural soil conditions, and not subject to agriculture practices. They can be divided into:

Closed forests - Characterised by crown cover higher than 40%

Open forest - Characterised by crown cover between 10 and 40%.

Degraded forests or grasslands - Forests or grasslands that are have been overused or poorly managed and are likely to have reduced biomass densities.

Protected forests or grasslands - Forests or grasslands that are designated as national parks or in other ways are legally protected.

TABLE 5-1
TYPES OF TROPICAL FORESTS AND REGIONAL FOREST FORMATIONS

Types of tropical forests[a]						
	Wet	Moist with short dry season	Moist with long dry season	Dry	Montane Moist	Montane Dry
	R ≥ 2000	2000>R>1000		R<1000	R>1000	R<1000
Forest	Mainly evergreen	Mainly moist deciduous	Mainly dry deciduous	Very dry deciduous	Mainly evergreen	Mainly dry deciduous
Typical regional forest formations:						
Africa	Lowland rain forests	Lowland evergreen to semi-ever-green forests	Dry deciduous forests and miombo woodlands	Deciduous forests and woodlands. Very dry savanna and steppe	Montane evergreen forests	Scrub forests and evergreen to semi-evergreen thickets
Asia	Tropical lowland evergreen rain forests	Dense semi-deciduous or deciduous forests	Dry deciduous forests	Low deciduous forests. Thorn forests	Tropical and wet and moist forests	Dry evergreen forests or pseudo-steppic vegetation
America	Ombrophilous forests	Evergreen seasonal forests.	Tropical and subtropical forests Cerrados or pantanal	Open deciduous forests	Tropical evergreen and/or seasonal forests	Dry deciduous forests or shrub savanna. Arid subdesertic matorrales
Open formations of the different climatic zones:						
Open Forest	Mainly evergreen degraded	Mainly moist deciduous	Mainly woodlands and tree savanna	Dry woodlands and tree savanna	Mainly degraded evergreen and seasonal	Mainly dry savannas

Note: R= annual rainfall in mm/yr

[a] The ecological conditions which characterise these main vegetation cover classes are:

Wet - Evergreen dense forests which receive more than 2000 mm per year rainfall evenly throughout the year.

Moist with short dry season - Deciduous forests, characterised by a short dry season (<4-5 months), and rainfall 1000-2000 mm per year.

Moist with long dry season - Woodlands and open forests, characterised by a long dry period (>5 months), and rainfall 1000-2000 mm per year.

Dry- Woodlands and tree savannas which receive less than 1000 mm per year of rainfall, very seasonally distributed.

Montane moist and dry- Main features of this zone are altitude above 1000 metres and rainfall above and below 1000 mm per year respectively.

5.1.4 Relationships among Categories

It is possible that some areas of land can fit the definitions of two categories - e.g., abandoned lands regrowing and changes in woody biomass stocks - simultaneously. In this situation, the most recent, significant human interaction should be used to allocate land into categories. Even though an area may have been abandoned and allowed to regrow, if it subsequently begins to be "managed" (e.g., as a significant source of fuelwood) it should be reclassified in the *changes in forest and other woody biomass stocks* category. It is important to recognise some key linkages and interactions both among components of the land-use change and forestry methods and with other calculations discussed in other chapters. Figure 5-1 illustrates a number of complicated relationships among these categories and also with biomass fuel combustion which is covered in the energy source category. Key linkages which should be understood are:

1. To estimate CO_2 emissions from *burning of cleared forests*, it is only necessary to know the total amount of biomass which is burned in the Inventory Year.

2. However, it is necessary to divide this burning into on-site and off-site (fuelwood) portions for two reasons:

   First, the type of burning affects the emissions of non-CO_2 trace gases such as CH_4 so that different emission factors may be applied to open burning on-site and to fuelwood use off-site.

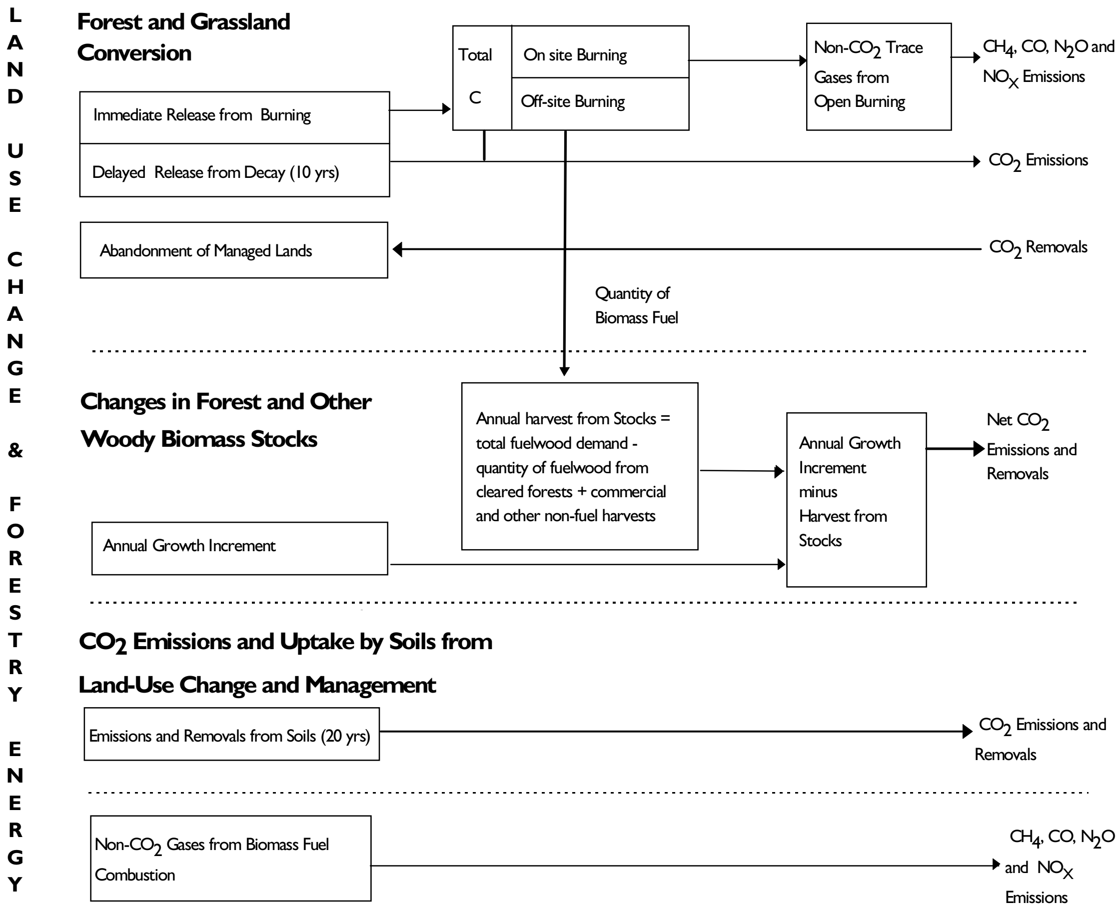
   Secondly, the amount of fuelwood removed from cleared forests must be deducted from the total biomass cleared to prevent double counting in the fuelwood consumption calculations. This is only an issue for those countries which must infer some or all of forest harvest from wood consumption surveys.

3. Fuelwood Consumption Information. Countries which have accurate and complete statistics on direct harvesting of all types of wood from biomass stocks, and all uses of biomass for fuel, should use locally available data. Many countries, however, have significant amounts of wood removed from forests, primarily for domestic fuel use, which are not accounted for in commercial harvest statistics. For these countries, a Fuelwood Consumption Accounting approach is provided which uses data from the FAO Yearbook of Forest Products.

   Fuelwood consumption information is used in two ways:

   – for estimating non-CO_2 trace gas emissions from biomass fuel combustion (in the Energy Section of the methodology); and
   – total wood consumption, corrected to deduct any wood which has come from forest clearing, is also a key input to the calculations of net CO_2 emissions or removals from *changes in forest and other woody biomass stocks*.

FIGURE 5-1 : RELATIONSHIPS AMONG CATEGORIES



5.1.5 Chapter Organisation

The remainder of this chapter presents methods for calculating GHGs from land-use change and forestry in two stages. The next section, *Basic Calculations*, presents initial simple calculations for each of three broad categories of forestry and changes in land use identified above. These categories also correspond directly to the subsections of the Land-use Change and Forestry Module of the *Workbook*.

The second stage, *Refinements in Calculations*, discusses a range of complexities and refinements which ideally could be included in such calculations, as data and understanding permit, in order to improve accuracy and completeness. These possible refinements include more detailed treatment of some aspects of the basic categories of land uses and land-use changes, as well as additional categories, which can affect carbon stocks and are potentially important for other GHGs. Issues discussed include the delayed release (or uptake) of non-CO_2 trace gases after burning of forests (either as a prescribed forest management tool or as a means of land-clearing), forest degradation, traditional shifting cultivation, and conversion of wetlands to other land uses or the reverse. These activities and other refinements can be incorporated in more detailed versions of the calculations.

A *Technical Appendix*, as mentioned, is also provided, which deals with sources of information on rates of land-use change, a critical activity data input for calculating GHG emissions.

5.2 Basic Calculations

5.2.1 Introduction

The basic calculations focus primarily on the land-use changes (causing changes in land cover) and land-use activities (forestry) that result in the largest, potential flux of CO_2 to the atmosphere or have the largest potential for sequestering carbon.

Two categories of land-use change are considered:

- forest and grassland conversion to agricultural lands
- abandonment of managed lands

In contrast to most GHG emission methodologies, estimating sources and sinks of CO_2 from land-use change requires the consideration of events over a long period of time. When forests are cleared or agricultural lands abandoned, the biological responses result in "commitments" of fluxes of carbon to or from the atmosphere for many years after the land-use change. This methodology is designed to produce an emissions estimate that is comparable to other elements of the inventory, fossil fuel emissions, for example. That is, it attempts to quantify the flux to or from the atmosphere *in the Inventory Year*. To do this, it is necessary to obtain estimates of land-use change activities for many years prior to the Inventory Year, and estimate the effects of these activities on the current year fluxes. The two selected categories are considered to be the most important land-use changes affecting CO_2 fluxes, but are not a comprehensive set. Many relevant land-use changes are excluded from the basic calculations. These are discussed in the last section of this chapter.

Relevant forestry (on-going land use) activity is combined in one very broad category, *changes in forest and other woody biomass stocks*, which is defined to include a wide variety of practices. Key examples are establishing and harvesting plantations, commercial forest management and harvesting, fuelwood gathering, and use of harvested wood.

Conceptually, this category is intended to account for all significant human interactions with forests and other woody biomass stocks which affect CO_2 fluxes to and from the atmosphere, but which do not result in a land-use change. It is intended to account, at least on a crude level, for all existing forests, but two comments are important here.

1. Natural, unmanaged (for wood products) forests are not considered to be either an anthropogenic source or sink, and are excluded from the calculations. However, in most countries of the world, a few undisturbed (by humans) forests exist, and they could still be sequestrating carbon as they regrow to a mature forest. The lack of consideration of these "undisturbed" forests in the tropics, for example, could lead to an underestimation of carbon sinks in this region. Tropical countries need to establish a permanent forest inventory monitoring network to determine if the "undisturbed" forests are sinks or not. Current research in the Amazon countries suggest some undisturbed forests are carbon sinks (Lugo and Brown, 1992; and Grace et al., 1995).

2. Forests regrowing naturally on abandoned lands are a net carbon sink attributable to past human activities and are accounted for separately. "Abandoned" lands are by definition assumed not to be subject to ongoing human intervention (of significance to carbon stocks) after abandonment.[8]

NOTE: Forests classified as natural, or abandoned/regrowing, can be excluded from the woody biomass stocks accounting only if there is no significant current human interaction with these forests. If they are being used as a source of fuelwood, or are being affected in other ways by ongoing human activities, they should be accounted for on an annual basis as part of *changes in forest and other woody biomass stocks*. In many countries, lands which are classified as natural or abandoned are in fact harvested informally. Thus, in some countries or regions with fuelwood shortages, little forest will actually fall into the natural or abandoned categories.

Several simplifying assumptions are made in the basic calculation methodology. A number of refinements are possible to improve on these basic calculations. One important option is to implement the basic calculations at a more detailed level of subcategories or geographic detail. National experts are strongly encouraged to do so if data are available. Box 3 discusses possibilities for adapting the methodology to various levels of detail, depending on the capabilities and data available to the user, and the relative importance of various components to the individual country.

Other possibilities for improving the accuracy and completeness of the basic calculations are possible. For example, the fate and amount of belowground biomass (roots, etc.) is currently ignored in the calculation. The section entitled *Refinements to Calculations*, later in this chapter, reviews a number of possible additions and refinements.

[8] Abandoned lands which are regrowing naturally may be cleared again. In this case, they should shift again to cleared lands, probably with a lower value for preclearing biomass density than when they were first cleared.

BOX 3
ALTERNATIVE LEVELS OF DETAIL

For simplicity and clarity, this chapter discusses calculation of emissions at a national level and for a relatively small number of subcategories within each category of land-use change and forestry. The level of detail in the subcategories is designed to match the available sources of default input data, carbon contents and other assumptions. It is important, however, for users of these emissions methodology guidelines to understand that they are not only permitted but encouraged to carry out the GHG emissions inventory calculations at a finer level of detail, if possible. Many countries have more detailed information available about land-use change, forests and agriculture, than was used in constructing default values here. It may be important in such countries to carry out emissions calculations at finer levels in two ways:

1. Geographic detail at a regional, rather than a national, level

If data are available, experts may find that GHG estimation for various regions within a country are necessary to capture important geographic variations in ecosystem types, biomass densities, fractions of cleared biomass which are burned, etc.

2. Finer detail by subcategory

If data are available, experts may subdivide the recommended activity categories and subcategories to reflect important differences in ecology or species, land use or agricultural practices, bioenergy consumption patterns, etc.

In all cases, working at finer levels of disaggregation does not change the basic nature of the calculations, although additional data and assumptions will generally be required beyond the defaults provided in the chapter. Once GHG emissions have been calculated at whatever is determined by the national experts to be the most appropriate level of detail, results should also be aggregated up to the national level and the standard categories requested in the IPCC proposed methodology. This will allow for comparability of results among all participating countries. Generally, the data and assumptions used for finer levels of detail should also be reported to the IPCC to ensure transparency and replicability of methods. *Volume 1: Reporting Instructions* discusses these issues in more detail.

5.2.2 Changes in Forest and Other Woody Biomass Stocks

The category *changes in forest and other woody biomass stocks* as used in these basic calculations is very broad, potentially including a wide variety of land-use practices. This discussion focuses heavily on changes in forests, which globally account for the largest component of annual changes in biomass stocks. However, other types of biomass such as non-forest trees (e.g., in villages, cities, etc.) and woody shrubs in grasslands should be included when they are a significant component of total changes in biomass stocks, as is likely to be the case for some specific countries. A basic organising concept in this chapter is that all existing forests can be allocated into one of three categories.

1. Natural, undisturbed forests, where they still exist and are in equilibrium, should not be considered either an anthropogenic source or sink. They can therefore be excluded from national inventory calculations.

   NOTE: Many countries may have little or no forests or woody biomass stocks which are not affected significantly by humans. In areas with severe fuelwood shortages, for example, significant biomass - and hence carbon - may be removed for fuel annually even from "natural forests" and abandoned lands.[9]

2. Forests regrowing naturally on abandoned lands are a net carbon sink attributable to past human activities and are accounted for as discussed in a later section. While the current regrowth is considered a response to past anthropogenic activity, "abandoned" lands are by definition assumed not to be subject to ongoing human intervention (of significance to carbon stocks) after abandonment.

3. All other types of forest are included in the changes in forest and other woody biomass stocks category. That is, any forest which experiences periodic or on-going human interventions that affect carbon stocks should be included here. In the basic calculations, the chapter focuses primarily on a few types of human interactions with forests which are believed to result in the most significant fluxes of carbon. National experts are encouraged, however, to estimate emissions for any activity related to existing forests which is considered to result in significant carbon emissions or removals, and for which necessary data are available. Any such activities falling within our broad definition of *changes in forests and other woody biomass stocks* should be included in this category and reported to the IPCC as discussed in *Volume 1: Reporting Instructions*.

Some of the activities in the changes in forest and other woody biomass stocks category which can potentially produce significant carbon fluxes are:

- management of commercial forests - including logging, restocking, selective thinning, etc., as practised by commercial forest products industries
- establishment and management of commercial plantations[10]
- other afforestation, and reforestation programmes
- informal fuelwood gathering

This category also includes trees which may not traditionally be considered part of "forests". It can include village and farm trees if these are important for biomass and biofuel accounting in some developing countries. It can also include urban trees, trees

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[9] Also, as discussed in the chapter introduction, there are likely to be widespread human induced effects, e.g., CO_2 fertilisation and nitrogen deposition, which cause changes in virtually all terrestrial biological systems. In this sense, there may be no natural forests which are not subject to human induced GHG emissions or removals. However, at present, the understanding of these broad effects is so uncertain, and quantitative estimation so difficult, that they are not included in the basic calculations recommended for all national inventories.

[10] Plantations are forest stands that have been established artificially, to produce a forest product "crop". They are either on lands that previously have not supported forests for more than 50 years (afforestation), or on lands that have supported forests within the last 50 years and where the original crop has been replaced with a different one (reforestation) (Brown et al., 1986).

planted along highways, aircraft runways, etc., if these are considered significant for a particular country's biomass calculations. These dispersed trees do not contribute greatly to carbon fluxes to or from the atmosphere on a global scale. However, in some countries, they may be important in accounting for the total amount of wood used for fuel. Also, they may be of interest to some countries because of their potential use in response strategies. For these reasons, they are included in the basic calculation methods. National experts who feel they are important, and have the necessary locally available data, can include them.

In addition to trees in non-forest locations, in some countries, woody biomass from shrubs or other plants, in grasslands or other locations, may play a significant role in total fuelwood supply. If this is the case, the annual supply of biomass from these "non-trees" must be included in the overall fuelwood accounting. Otherwise the loss of biomass stocks in forests may be overstated.

As illustrated in the above list, the changes in forest and other woody biomass stocks category includes some tree planting activities which, strictly speaking, are land-use **changes**. Plantation establishment and other afforestation/reforestation programmes are examples. It is recognised that this is conceptually inconsistent as the category is intended to account for ongoing interactions with existing forests. However, from a pragmatic perspective, including these activities within the category can simplify the calculations. These subcategories are land-use changes which create new forest stocks. As soon as the land-use change occurs (i.e., the tree planting), the new land use becomes part of the *changes in forest and other woody biomass stocks* category which is accounted for on an annual incremental basis. Although it would be possible, it is not necessary to estimate the lagged effects of this change as is done with other land-use changes.[11] While including such a range of tree-related activities in one category may introduce some confusion, the calculation procedure is basically the same for all subcategories, and this allows the simplest possible set of emissions calculations.

As discussed above, if lands previously considered abandoned and regrowing, or natural forests, are being affected by human activity in the inventory year, they should be reclassified into the *changes in forest and other woody biomass stocks* category.

As discussed in the *Overview*, the methodology is designed to accommodate users at several levels of detail. This is especially important in the managed forests category. Possible levels include:

1. A simple first order approach, covering the main subcategories, with calculations based on simple default assumptions and default data provided.

   NOTE: An inventory of land-use change and forestry emissions developed on default values only is unlikely to be considered credible for any country which has significant emissions or activities in these areas.

2. Calculations at the same level of detail but substituting more appropriate data and assumptions from local sources.

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[11] There is one omission in this accounting which may be important for some countries. If plantations are established on previously unforested lands, there may be a long term accumulation of carbon in the soil as a result of the land-use change. This would not normally be picked up in the simple *changes in forest and other woody biomass stocks* calculations. It could be added if national experts have detailed data on the pre-plantation land uses, the soil carbon contents and rates of accumulation, etc.

3. Calculations following the same structure, but broken down to finer levels of detail to improve accuracy and utility of estimates, where locally available data can support this.

4. Estimates derived from much more detailed and precise inventory-based forest accounting methods. These results can be reformatted and **presented** in the form of calculations comparable to those used by the other national experts operating with less detailed data.

It is highly desirable that the methodology be relevant for countries which have access to much more detailed data on changes in forest stocks. Some countries with highly developed forestry industries do in fact keep track of existing commercial forests through periodic detailed surveys For such countries, it is possible to derive from survey results aggregate values comparable to the data and assumptions used in the simple approach, and present them in this common format. This will assist all interested parties in evaluating various national estimates on a comparable basis, and will thus be necessary to comply with requirements of *Volume 1: Reporting Instructions*. Box 4 provides some further discussion of these procedures.

Box 4
ADAPTING DETAILED FOREST INVENTORY DATA TO THE IPCC FORMAT

A number of countries with highly developed commercial forestry industries routinely collect forest biomass data at a detailed inventory level which allows for relatively precise and direct assessment of the changes in biomass stocks, and equivalent carbon fluxes. National experts working with data of this kind should be able to derive from it values equivalent to those used in calculating emissions with the IPCC methodology.

Regardless of how detailed the data base used may be, the results ultimately must be presented in units (e.g. Gg) of carbon and CO_2 emitted or removed in a given average response category (e.g., annual biomass growth rates by ecosystem type). Similarly, the number of hectares of forest in various types can be aggregated up to categories matching the simple approach outlined here. The amount of biomass removed as commercial harvest or for other reasons, should also be relatively well established in such inventories. With these data, it should be possible to, in effect, work backwards to derive the necessary input assumptions and aggregate values. For example, national experts might start with a change in total biomass for specified forest types (and/or regions) over a specified time period. Then they could add the amounts of biomass removed through commercial harvest or for other reasons (e.g., thinning), to get the total growth of biomass over the period. This could then be divided by the number of kilohectares in the category (and the number of years, if a multi-year period) to get average annual growth rates by category. This would then provide all the values needed to reconstruct the calculations in a comparable form to those from countries with minimal data.

The national emission/removal estimates presented in this form would then be easily understood and compared by all other parties involved in the international climate change discussions. The intent is to provide a calculation and reporting framework which can accommodate users with vastly different levels of data available, yet allow them to present the results on a comparable basis.

Changes in forest and other woody biomass stocks may be either a source or a sink for carbon dioxide for a given year and country or region. The simplest way to determine which, is by comparing the annual biomass growth versus annual harvest, including the decay of forest products and slash left during harvest. Decay of biomass damaged or killed during logging results in short-term release of CO_2. For the purposes of the basic calculations, the recommended default assumption is that all carbon removed in wood and other biomass from forests is oxidised in the year of removal. This is clearly not strictly accurate in the case of some forest products, but is considered a legitimate, conservative assumption for initial calculations. Box 5 provides some further discussion of this issue.

BOX 5
THE FATE OF HARVESTED WOOD

Harvested wood releases its carbon at rates dependent upon its method of processing and its end-use: waste wood is usually burned immediately or within a couple of years, paper usually decays in up to 5 years (although landfilling of paper can result in longer-term storage of the carbon and eventual release as methane or CO), and lumber decays in up to 100 or more years. Because of this latter fact, forest harvest (with other forms of forest management) could result in a net uptake of carbon if the wood that is harvested is used for long-term products such as building lumber, and the regrowth is relatively rapid. This may in fact become a response strategy.

For the initial calculations of CO_2 emissions from changes in forest and other woody biomass stocks, however, the recommended default assumption is that all carbon in biomass harvested is oxidised in the removal year. This is based on the perception that stocks of forest products in most countries are not increasing significantly on an annual basis. It is the net change in stocks of forest products which should be the best indicator of a net removal of carbon from the atmosphere, rather than the gross amount of forest products produced in a given year. New products with long lifetimes from current harvests frequently replace existing product stocks, which are in turn discarded and oxidised. The proposed method recommends that storage of carbon in forest products be included in a national inventory only in the case where a country can document that existing stocks of long term forest products are in fact increasing.

If data permit, one could add a pool to Equation 1 (1) in the changes in forest and other woody biomass stocks calculation to account for increases in the pool of forest products. This information would, of course, require careful documentation, including accounting for imports and exports of forest products during the inventory period.

The net growth of biomass stocks (and accumulation of carbon) depends on the type of biomass stock and the intensity of harvesting. Well managed commercial forests, replacing natural forests, would over the long term be expected to have net emissions close to zero. In many cases, where historically cleared areas are regrowing under commercial management, with limited logging, the forest areas are currently a net sink. If forests (or parts of forests) are logged or harvested at a rate which exceeds regrowth, then there is a net loss of carbon.[12]

Establishment of plantations and other tree planting activities result in absorption of CO_2 from the atmosphere and storage of this carbon until the vegetation is burned or decays. Restocking of managed forests, planting of urban, village and farm trees, and establishing plantations on unforested lands, therefore, result in an uptake of carbon from the atmosphere, at least until the biomass is harvested and enters a decay pool, or the system reaches maturity. The effect of plantation establishment can be to create a net sink for carbon even if the plantation is harvested for products that are rapidly oxidised (e.g., fuelwood). If the plantations are harvested so that there is no net loss of biomass over time (i.e., harvested in a sustainable fashion), then the rate of carbon accumulation on land is positive (or at least non-negative) and tied directly to changes in the area of plantations and their average biomass.

The conversion of natural forests to plantations may result in an initial loss of biomass carbon due to an initial reduction in standing biomass. If plantations are established by first clearing existing forests, the initial loss should appear under *forest and grassland conversion* below. Reaccumulation of biomass in these plantations in subsequent years would be accounted for here under *changes in forest and other woody biomass* stocks. The approach accounts for all plantations in operation in the inventory year, including both previously planted and newly established plantations.

The method for calculating the net changes in biomass stocks is shown in Equation 1. For non-forest trees such as village and farm trees, accounting would be done on the basis of numbers of trees (e.g., in thousands) rather than for hectares of land. The calculations would be the same, except that average annual growth would be expressed in tonnes dm per thousand trees rather than per hectare.

The recommended unit of calculation is tonnes of dry biomass, and it is necessary to convert to carbon for emissions estimation. A general default value of 0.50 tonnes-C/tonne dry biomass is recommended for all biomass calculations. If more accurate conversion values are available for the particular system, these should of course be used.

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[12] In addition, logging provides access to previously inaccessible forests, thereby facilitating degradation of forests by activities such as fuelwood collection, habitation, and agricultural activity.

EQUATION 1

(1) hectares of land in a particular category (e.g., plantations)

x

average annual growth per hectare in biomass

=

gross annual growth increment.

total biomass increment is the sum of all relevant categories.

(2) total harvest by category (including fuelwood gathering)

x

expansion ratio to treat slash

=

gross annual biomass loss.

total harvest and other biomass loss is the sum of all relevant categories of harvest.

(3) total annual growth increment - total annual biomass loss

=

annual biomass change (positive or negative).

Growth Increments

Estimates of average annual accumulation of dry matter as biomass per hectare are presented for forests naturally regrowing by broad category in Table 5-2. These values can be used as default values for growth rates in similar managed forest categories if no other information is available. For forests which are more intensely managed (e.g., with periodic thinning, restocking, etc.) annual growth increments could be quite different. Values for some typical plantation species are presented in Table 5-3 and can be used as default values. As discussed in notes in these tables, average growth rates represent a great deal of variability within regions and even from site to site. It is always strongly recommended that locally available data be used or developed if possible in national inventory calculations.

TABLE 5-2
ANNUAL AVERAGE ABOVEGROUND BIOMASS UPTAKE BY NATURAL REGENERATION
(tonnes dm/ha)

Tropical Regions		Forest Types					
		Moist Forests		Seasonal Forests		Dry Forests	
		0-20 Years	20-100 Years	0-20 Years	20-100 Years	0-20 Years	20-100 Years
	America	8.0	0.9	5.0	0.5	4.0	0.25
	Africa	11	1.0	7.0	0.7	4.0	0.25
	Asia	11	1.0	7.0	0.7	4.0	0.25

Note: Growth rates are derived by assuming that tropical forests regrow to 70% of undisturbed forest biomass in the first twenty years. All forests are assumed to regrow to 100% of undisturbed forest biomass in 100 years. Assumptions on the rates of growth in different time periods are derived from Brown and Lugo (1990).

		0-20 Years	20-100 Years
Temperate Forests			
	Evergreen	3.0	3.0
	Deciduous	2.0	2.0
Boreal Forests		1.0	1.0

Note: Temperate and boreal forests actually require considerably longer than 100 years to reach the biomass density of a fully mature system. Harmon et al. (1990), for example, report carefully designed simulations indicating that a 100-year old stand of Douglas fir would contain only a little over half the biomass of a 450-year old growth stand of the same species. There is also evidence that growth rates in temperate and boreal systems are more nearly linear over different age periods than is the case in tropical systems. Nabuurs and Mohren (1993) suggest that growth rates for several different species in temperate and boreal zones rise slowly to peak at ages of 30-55 years and decline slowly thereafter. This suggests that using the same default values for 0-20 year and 20-100 years may be a reasonable first approximation. Nabuurs and Mohren (1990) also illustrate that growth rates may vary as much as a factor of ten for stands of the same species and age, depending on site-specific conditions. The table values are very general representative global values from Houghton et al. (1983 and 1987).

ALL OF THESE REGIONAL AVERAGE GROWTH RATES SHOULD BE CONSIDERED INDICATIVE ONLY. IF FORESTS ARE A SIGNIFICANT PART OF A COUNTRY'S TOTAL GHG INVENTORY, LOCALLY AVAILABLE DATA OR EXPERT JUDGEMENT SHOULD BE SOUGHT TO DEVELOP VALUES REFLECTING CONDITIONS AND PRACTICES.