Regional workshop: "Capacity Development for Sustainable National Greenhouse Gas Inventories – AFOLU sector (CD-REDD II) Programme

General methods for estimating stock changes in carbon pools

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Carbon Pools

Currently 5 carbon pools have to be reported under the UNFCCC:

Above-ground Biomass Below-ground Biomass	} Biomass
Dead Wood Litter	} Dead Organic Matter (DOM)
Soil Organic Matter (SOM)	{ mineral soils organic soils

A sixth pool can be voluntarily reported:

- Harvested Wood Product (HWP)

Carbon Pools

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

Pool		Description
Biomass	Above-ground biomass	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage. Note: In cases where forest understory is a relatively small component of the above-ground biomass carbon pool, it is acceptable for the methodologies and associated data used in some tiers to exclude it, provided the tiers are used in a consistent manner throughout the inventory time series.
	Below-ground biomass	All biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.
Dead organic matter	Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter (or the diameter specified by the country).
	Litter	Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g. 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.
Soils	Soil organic matter[1]	Includes organic carbon in mineral soils to a specified depth chosen by the country and applied consistently through the time series[2]. Live and dead fine roots and DOM within the soil, that are less than the minimum diameter limit (suggested 2 mm) for roots and DOM, are included with soil organic matter where they cannot be distinguished from it empirically. The default for soil depth is 30 cm and guidance on determining country-specific depths is given in Chapter 2.3.3.1.

[1] Includes organic material (living and non-living) within the soil matrix, operationally defined as a specific size fraction (e.g., all matter passing through a 2 mm sieve). Soil C stock estimates may also include soil inorganic C if using a Tier 3 method. CO_2 emissions from liming and urea applications to soils are estimated as fluxes using Tier 1 or Tier 2 method.

[2] Carbon stocks in organic soils are not explicitly computed using Tier 1 or Tier 2 method, (which estimate only annual C flux from organic soils), but C stocks in organic soils can be estimated in a Tier 3 method. Definition of organic soils for classification purposes is provided in Chapter 3.

Carbon Stock Changes in Land-Use categories

Emissions and removals of CO_2 for the AFOLU Sector, based on changes in ecosystem C stocks, are estimated for each land-use category (including both land remaining in a land-use category as well as land converted to another land use).

Applying the same equation to each land-use category results in

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{OL}$$

Carbon Stock Changes in Land-Use categories

- For each land-use category, carbon stock changes are estimated for all *strata* or subdivisions of land area

- Subdivisions should be done according to differences in the carbon dynamic and in the magnitude of ecosystem C stocks (e.g. forest typology, ecotype, soil type, management regime etc.) within a land-use category.

EQUATION 2.2

ANNUAL CARBON STOCK CHANGES FOR A LAND-USE CATEGORY AS A SUM OF CHANGES IN EACH STRATUM WITHIN THE CATEGORY

$$\Delta C_{LU} = \sum_i \Delta C_{LU_i}$$

Where:

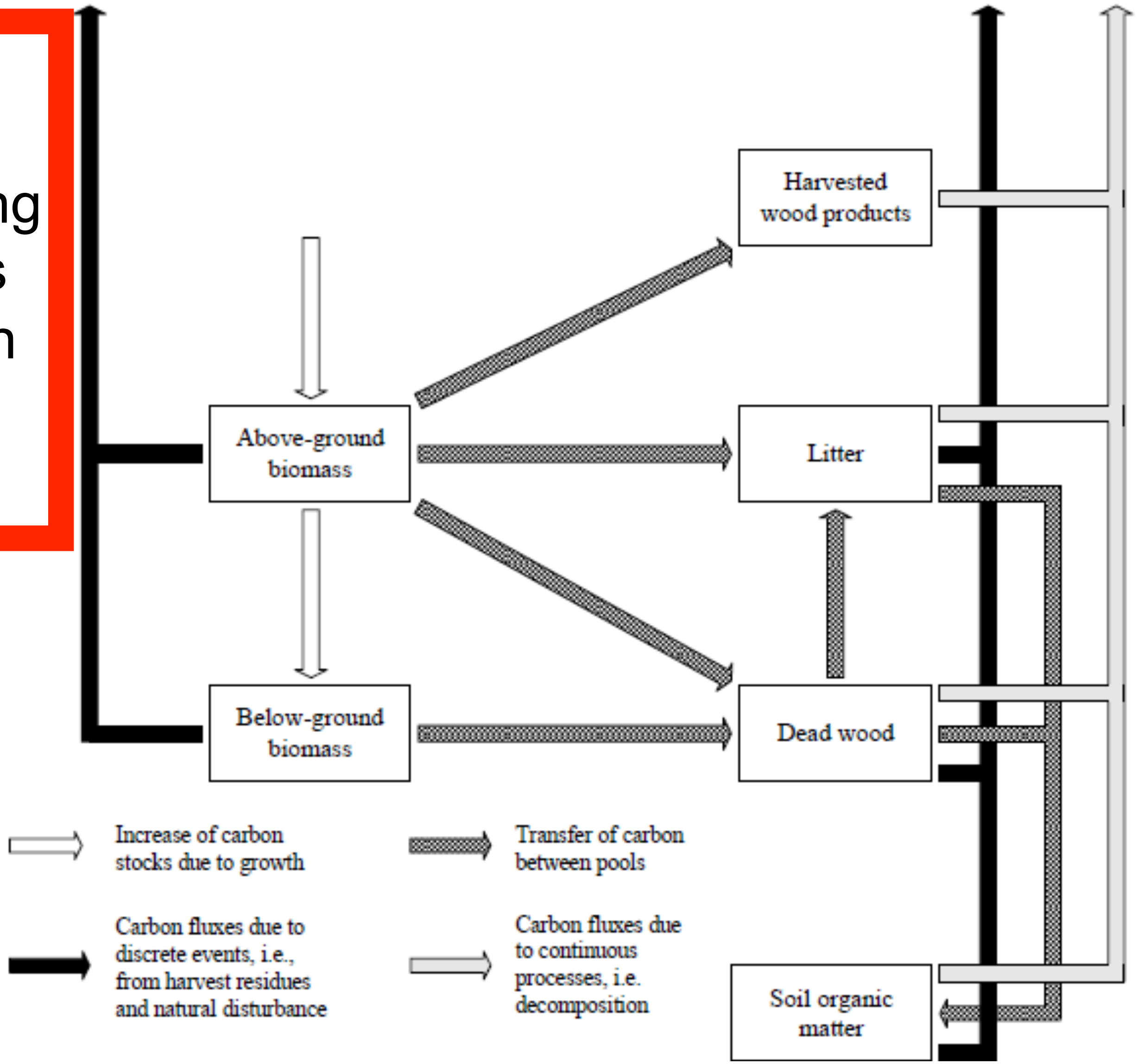
ΔC_{LU} = carbon stock changes for a land-use (LU) category as defined in Equation 2.1.

i = denotes a specific stratum or subdivision within the land-use category (by any combination of species, climatic zone, ecotype, management regime etc., see Chapter 3), i = 1 to n.

Carbon fluxes

Figure 2.1 Generalized carbon cycle of terrestrial AFOLU ecosystems showing the flows of carbon into and out of the system as well as between the five C pools within the system.

Carbon stock changes within a stratum are estimated by considering carbon cycle processes between the five carbon pools



Carbon fluxes

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

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

Stock Change in Carbon Pools

Carbon stock changes are summarized by the following equation

$$\Delta C_{LUi} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO} + \Delta C_{HWP}$$

Where:

ΔC_{LU_i} = carbon stock changes for a stratum of a land-use category

Subscripts denote the following carbon pools:

AB = above-ground biomass

BB = below-ground biomass

DW = deadwood

LI = litter

SO = soils

HWP = harvested wood products

Tier Level

FRAMEWORK OF TIER STRUCTURE FOR AFOLU METHODS

Tier 1 methods are designed to be the simplest to use, for which equations and default parameter values (e.g., emission and stock change factors) are provided by IPCC. Country-specific activity data are needed, but there are often globally available sources of activity data estimates (e.g. FAO), although these data are usually spatially coarse.

Tier 2 can use the same methodological approach as Tier 1 but applies emission and stock change factors that are based on country- or region-specific data, for the most important land-use or livestock categories. Higher temporal and spatial resolution and more disaggregated activity data are typically used in Tier 2.

At **Tier 3**, higher order methods are used, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national level.

Tier 1

Because of limitations to deriving default data sets for supporting estimates of some stock changes, Tier 1 methods include several simplifying assumptions:

• change in below-ground biomass C stocks are assumed to be zero under Tier 1 (under Tier 2, country-specific data on ratios of below-ground to above-ground biomass can be used to estimate below-ground stock changes);

• under Tier 1, dead wood and litter pools are often lumped together as 'dead organic matter'; and

• dead organic matter stocks are assumed to be zero for non-forest land-use categories under Tier 1. For Forest Land converted to another land use, default values for estimating dead organic matter losses are provided in Tier 1.

Tier 1

- Disturbances may also have long-lasting effects, such as decay of burnt trees. For practicality, Tier 1 assumes that all post-disturbance emissions (less removal of harvested wood products) are estimated as part of the disturbance event, i.e., in the year of the disturbance. For example, rather than estimating the decay of dead organic matter left after a disturbance over a period of several years, all lost biomass is estimated as oxidized in the year of the event.

- Under Tier 1, it is assumed that the average transfer rate into dead organic matter (dead wood and litter) is equal to the average transfer rate out of dead organic matter, so that the net stock change is zero. Countries experiencing significant changes in forest types or disturbance or management regimes should use higher Tier

Carbon stock changes estimation

• All estimates of changes in carbon stocks, i.e., growth, internal transfers and emissions, are in units of carbon to make all calculations consistent.

Carbon gains (removals and transfer to the accounted pool) have a positive sign (+) while losses (emissions and transfers from the accounted pool) have negative sign (-)

Data on biomass stocks, increments, harvests, etc. can initially be in units of dry matter that need to be converted in units of carbon before using for carbon stock changes estimation.

• However, emissions and removals are then converted in Gg of CO_2equivalent to make these comparable with the GHG fluxes of other sectors. The conversion factor is $-\frac{44}{12}$

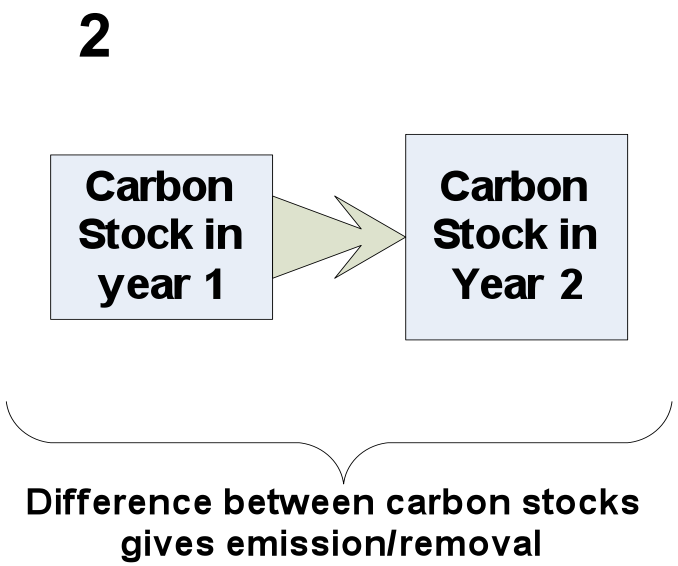
So that removals are negative quantities while emissions are positive

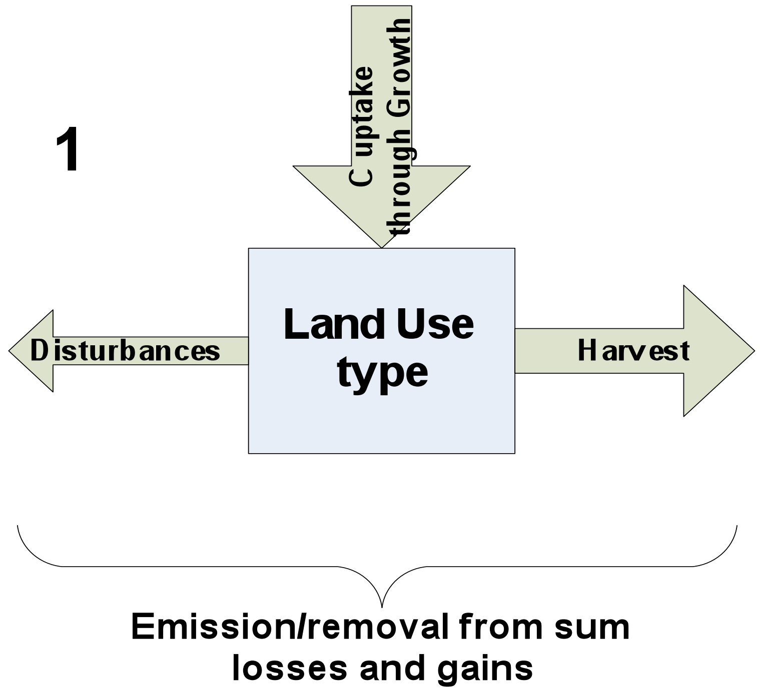
Carbon stock changes estimation

• There are two fundamentally different and equally valid approaches to estimating stock changes:

1) the process-based approach, which estimates the net balance of additions to and subtraction from a carbon stock;

2) the stock-based approach, which estimates the difference in carbon stocks at two points in time.





Carbon stock changes estimation

If the C stock changes are estimated on a per hectare basis, then the value is multiplied by the total area within each stratum to obtain the total stock change estimate for the pool

When using the Stock-Difference Method, it is important to ensure that the area of land in that category at times t_1 and t_2 is identical

It is good practice to use the area at the end of the inventory period (t_2) to define the area of land remaining in the land-use category

Carbon stock changes estimation

In applying the Gain-Loss or Stock-Difference Methods, the relevant area is the area of land remaining in the relevant category at the end of the year.

The length of time that land remains in a conversion category after a change in land use is by default 20 years (other periods may be used at higher Tiers according to national circumstances).

Under default assumptions therefore land will be transferred from a conversion category to a remaining category after it has been in a given land use for 20 years.

Stock changes that are completed within 1 year after conversion will be related to the area converted annually and the relevant land areas need to be treated as a sub-category within the conversion category.

Gains and Losses method

EQUATION 2.4
ANNUAL CARBON STOCK CHANGE IN A GIVEN POOL AS A FUNCTION OF GAINS AND LOSSES (GAIN-LOSS METHOD)

$$\Delta C = \Delta C_G - \Delta C_L$$

Where:

ΔC = Annual carbon stock change in the pool, tonnes C yr^{-1}

ΔC_G = Annual gain of carbon, tonnes C yr^{-1}

ΔC_L = Annual loss of carbon, tonnes C yr^{-1}

Stock Change method

EQUATION 2.5
CARBON STOCK CHANGE IN A GIVEN POOL AS AN ANNUAL AVERAGE DIFFERENCE BETWEEN ESTIMATES AT TWO POINTS IN TIME (STOCK-DIFFERENCE METHOD)

$$\Delta C = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)}$$

Where:

ΔC = Annual carbon stock change in the pool, tonnes C yr^{-1}

C_1 = Carbon stock in the pool at time t_1, tonnes C

C_2 = Carbon stock in the pool at time t_2, tonnes C

Changes in Living Biomass

Biomass is present in both aboveground and below-ground parts of annual and perennial plants.

Biomass associated with annual and perennial herbaceous (i.e., non-woody) plants and tissues (e.g. leaves) is relatively ephemeral, i.e., it decays and regenerates annually or every few years. So emissions from decay are balanced by removals due to re-growth making overall net C stocks in biomass rather stable in the long term.

Thus, the methods focus on stock changes in biomass associated with woody plants and trees, which can accumulate large amounts of carbon over their lifespan

Changes in Living Biomass

Increases in the biomass pools are due to photosynthesis;

While losses are caused by;

- human activities (i.e. harvesting) and disturbances (mainly fires);
- natural processes (i.e. disturbances) and mortality

For inventory purposes, changes in C stock in biomass are estimated for

(i) land remaining in the same land-use category;

(ii) land converted to a new land-use category.

All emissions and removals associated with a land-use change are reported in the new land-use category.

Changes in Living Biomass

The **Gain-Loss Method** requires the biomass carbon loss to be subtracted from the biomass carbon gain (increment).

For Tier 1 method default values for calculation of increment and losses are provided in the 2006 IPCC Guidelines. Higher tier methods use country-specific data.

For all tiers, country-specific activity data are required, although for Tier 1 these can be obtained from global databases (e.g. FAO statistics).

EQUATION 2.7

ANNUAL CHANGE IN CARBON STOCKS IN BIOMASS IN LAND REMAINING IN A PARTICULAR LAND-USE CATEGORY (GAIN-LOSS METHOD)

$$\Delta C_B = \Delta C_G - \Delta C_L$$

Where:

ΔC_B = annual change in carbon stocks in biomass (the sum of above-ground and below-ground biomass terms in Equation 2.3) for each land sub-category, considering the total area, tonnes C yr^{-1}

ΔC_G = annual increase in carbon stocks due to biomass growth for each land sub-category, considering the total area, tonnes C yr^{-1}

ΔC_L = annual decrease in carbon stocks due to biomass loss for each land sub-category, considering the total area, tonnes C yr^{-1}

Changes in Living Biomass

EQUATION 2.15

ANNUAL CHANGE IN BIOMASS CARBON STOCKS ON LAND CONVERTED TO OTHER LAND-USE CATEGORY (TIER 2)

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

Where:

ΔC_B = annual change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr^{-1}

ΔC_G = annual increase in carbon stocks in biomass due to growth on land converted to another land-use category, in tonnes C yr^{-1}

$\Delta C_{CONVERSION}$ = initial change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr^{-1}

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1}

Conversion to another land category may be associated with a change in biomass stocks, e.g., part of the biomass may be withdrawn through land clearing, restocking or other human-induced activities. These initial changes in carbon stocks in biomass ($\Delta C_{CONVERSION}$) are calculated with the use of Equation 2.16 as follows:

Changes in Living Biomass

EQUATION 2.16
INITIAL CHANGE IN BIOMASS CARBON STOCKS ON LAND CONVERTED TO ANOTHER LAND CATEGORY

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTER_i} - B_{BEFORE_i}) \bullet \Delta A_{TO\_OTHERS_i}\} \bullet CF$$

Where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks on land converted to another land category, tonnes C yr^{-1}

B_{AFTER_i} = biomass stocks on land type *i* immediately after the conversion, tonnes d.m. ha^{-1}

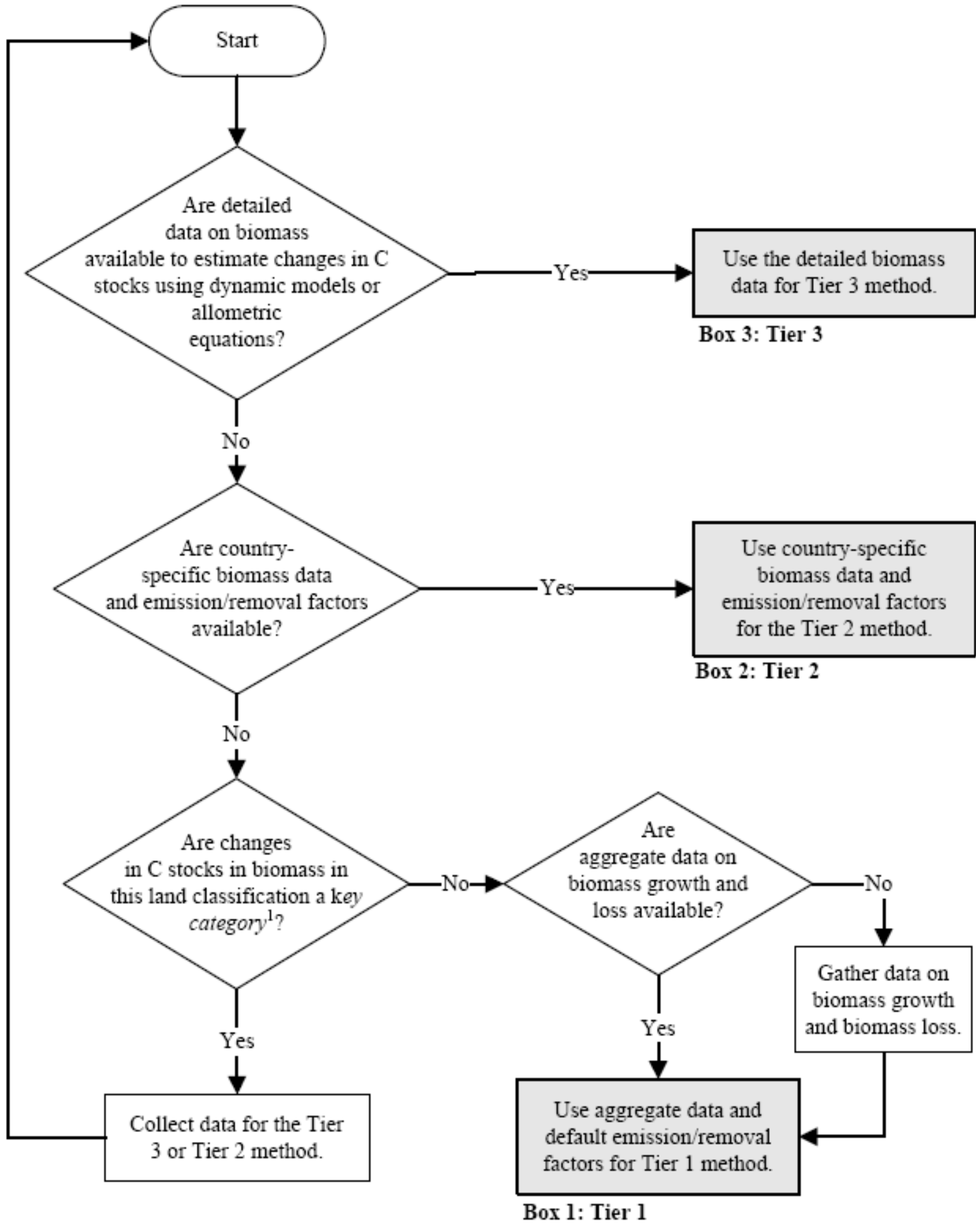
B_{BEFORE_i} = biomass stocks on land type *i* before the conversion, tonnes d.m. ha^{-1}

$\Delta A_{TO\_OTHERS_i}$ = area of land use *i* converted to another land-use category in a certain year, ha yr^{-1}

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

i = type of land use converted to another land-use category

Figure 2.2 Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in biomass in a land-use category.



Changes in Living Biomass

EQUATION 2.9

ANNUAL INCREASE IN BIOMASS CARBON STOCKS DUE TO BIOMASS INCREMENT IN LAND REMAINING IN THE SAME LAND-USE CATEGORY

$$\Delta C_G = \sum_{i,j} (A_{i,j} \bullet G_{TOTAL_{i,j}} \bullet CF_{i,j})$$

Where:

ΔC_G = annual increase in biomass carbon stocks due to biomass growth in land remaining in the same land-use category by vegetation type and climatic zone, tonnes C yr^{-1}

A = area of land remaining in the same land-use category, ha

G_{TOTAL} = mean annual biomass growth, tonnes d. m. ha^{-1} yr^{-1}

i = ecological zone (*i* = 1 to *n*)

j = climate domain (*j* = 1 to *m*)

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

Changes in Living Biomass

EQUATION 2.10

AVERAGE ANNUAL INCREMENT IN BIOMASS

Tier 1

$$G_{TOTAL} = \sum \{G_W \bullet (1 + R)\}$$ Biomass increment data (dry matter) are used directly

Tiers 2 and 3

$$G_{TOTAL} = \sum \{I_V \bullet BCEF_I \bullet (1 + R)\}$$ Net annual increment data are used to estimate G_W by applying a biomass conversion and expansion factor

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

G_W = average annual above-ground biomass growth for a specific woody vegetation type, tonnes d. m. ha^{-1} yr^{-1}

R = ratio of below-ground biomass to above-ground biomass for a specific vegetation type, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$. R must be set to zero if assuming no changes of below-ground biomass allocation patterns (Tier 1).

I_V = average net annual increment for specific vegetation type, m^3 ha^{-1} yr^{-1}

$BCEF_I$ = biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to above-ground biomass growth for specific vegetation type, tonnes above-ground biomass growth (m^3 net annual increment)$^{-1}$, (see Table 4.5 for Forest Land). If $BCEF_I$ values are not available and if the biomass expansion factor (BEF) and basic wood density (D) values are separately estimated, then the following conversion can be used:

$$BCEF_I = BEF_I \bullet D$$

Changes in Living Biomass

EQUATION 2.11

ANNUAL DECREASE IN CARBON STOCKS DUE TO BIOMASS LOSSES IN LAND REMAINING IN THE SAME LAND-USE CATEGORY

$$\Delta C_L = L_{wood-removals} + L_{fuelwood} + L_{disturbance}$$

Where:

ΔC_L = annual decrease in carbon stocks due to biomass loss in land remaining in the same land-use category, tonnes C yr^{-1}

$L_{wood-removals}$ = annual carbon loss due to wood removals, tonnes C yr^{-1} (See Equation 2.12)

$L_{fuelwood}$ = annual biomass carbon loss due to fuelwood removals, tonnes C yr^{-1} (See Equation 2.13)

$L_{disturbance}$ = annual biomass carbon losses due to disturbances, tonnes C yr^{-1} (See Equation 2.14)

Changes in Living Biomass

EQUATION 2.12

ANNUAL CARBON LOSS IN BIOMASS OF WOOD REMOVALS

$$L_{wood-removals} = \{H \bullet BCEF_R \bullet (1 + R) \bullet CF\}$$

Where:

$L_{wood-removals}$ = annual carbon loss due to biomass removals, tonnes C yr^{-1}

H = annual wood removals, roundwood, $m^3\ yr^{-1}$

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$. R must be set to zero if assuming no changes of below-ground biomass allocation patterns (Tier 1).

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

$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark), tonnes biomass removal (m^3 of removals)$^{-1}$, (see Table 4.5 for Forest Land). However, if $BCEF_R$ values are not available and if the biomass expansion factor for wood removals (BEF_R) and basic wood density (D) values are separately estimated, then the following conversion can be used:

$$BCEF_R = BEF_R \bullet D$$

If country-specific data on roundwood removals are not available, the inventory experts should use FAO statistics on wood harvest. FAO statistical data on wood harvest exclude bark. To convert FAO statistical wood harvest data without bark into merchantable wood removals including bark, multiply by default expansion factor of 1.15.

Changes in Living Biomass

EQUATION 2.13
ANNUAL CARBON LOSS IN BIOMASS OF FUELWOOD REMOVAL

$$L_{fuelwood} = [\{FG_{trees} \bullet BCEF_R \bullet (1+R)\} + FG_{part} \bullet D] \bullet CF$$

Where:

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

FG_{trees} = annual volume of fuelwood removal of whole trees, $m^3\ yr^{-1}$

FG_{part} = annual volume of fuelwood removal as tree parts, $m^3\ yr^{-1}$

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$; R must be set to zero if assuming no changes of below-ground biomass allocation patterns. (Tier 1)

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

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

$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to biomass removals (including bark), tonnes biomass removal (m^3 of removals)$^{-1}$, (see Table 4.5 for Forest Land). If $BCEF_R$ values are not available and if the biomass expansion factor for wood removals (BEF_R) and basic wood density (D) values are separately estimated, then the following conversion can be used:

$$BCEF_R = BEF_R \bullet D$$

Biomass Expansion Factors (BEF_R) expand merchantable wood removals to total aboveground biomass volume to account for non-merchantable components of the tree, stand and forest. BEF_R is dimensionless.

Changes in Living Biomass

EQUATION 2.14
ANNUAL CARBON LOSSES IN BIOMASS DUE TO DISTURBANCES

$$L_{disturbance} = \{A_{disturbance} \bullet B_W \bullet (1 + R) \bullet CF \bullet fd\}$$

Where:

$L_{disturbances}$ = annual other losses of carbon, tonnes C yr^{-1} (Note that this is the amount of biomass that is lost from the total biomass. The partitioning of biomass that is transferred to dead organic matter and biomass that is oxidized and released to the atmosphere is explained in Equations 2.15 and 2.16).

$A_{disturbance}$ = area affected by disturbances, ha yr^{-1}

B_W = average above-ground biomass of land areas affected by disturbances, tonnes d.m. ha^{-1}

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$. R must be set to zero if no changes of below-ground biomass are assumed (Tier 1)

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

fd = fraction of biomass lost in disturbance (see note below)

Note: The parameter fd defines the proportion of biomass that is lost from the biomass pool: a stand-replacing disturbance will kill all (fd = 1) biomass while an insect disturbance may only remove a portion (e.g. fd = 0.3) of the average biomass C density. Equation 2.14 does not specify the fate of the carbon removed from the biomass carbon stock. The Tier 1 assumption is that all of $L_{disturbances}$ is emitted in the year of disturbance. Higher Tier methods assume that some of this carbon is emitted immediately and some is added to the dead organic matter pools (dead wood, litter) or HWP.

Changes in Living Biomass

The **Stock-Difference Method** requires biomass carbon stock inventories for a given land area, at two points in time.

Annual biomass change is the difference between the biomass stock at time t_2 and time t_1, divided by the number of years between the inventories.

Factors are provided in the 2006 IPCC Guidelines to convert fresh wood volume to carbon mass units

EQUATION 2.8

ANNUAL CHANGE IN CARBON STOCKS IN BIOMASS IN LAND REMAINING IN THE SAME LAND-USE CATEGORY (STOCK-DIFFERENCE METHOD)

$$\Delta C_B = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)} \qquad \text{(a)}$$

Where:

ΔC_B = annual change in carbon stocks in biomass (the sum of above-ground and below-ground biomass terms in Equation 2.3) in land remaining in the same category (e.g., *Forest Land Remaining Forest Land*), tonnes C yr^{-1}

C_{t_2} = total carbon in biomass for each land sub-category at time t_2, tonnes C

C_{t_1} = total carbon in biomass for each land sub-category at time t_1, tonnes C

Check for Mass consistency

TABLE 2.1
EXAMPLE OF A SIMPLE MATRIX (TIER 2) FOR THE IMPACTS OF DISTURBANCES ON CARBON POOLS

From: \ To:	Above-ground biomass	Below-ground biomass	Dead wood	Litter	Soil organic matter	Harvested wood products	Atmo-sphere	Sum of row (must equal 1)
Above-ground biomass	A		B	C	D	E	F	1
Below-ground biomass								1
Dead wood								1
Litter								1
Soil organic matter								1

Enter the proportion of each pool on the left side of the matrix that is transferred to the pool at the top of each column. All of the pools on the left side of the matrix must be fully populated and the values in each row must sum to 1.

Impossible transitions are blacked out.

Note: Letters A to F are cell labels that are referenced in the text.

Check for Mass consistency

It is good practice to develop and use a disturbance matrix (Table 2.1) for each biomass, dead organic matter and soil carbon pool, the proportion of the carbon remaining in that pool, and the proportions transferred to other pools, to harvested wood products and to the atmosphere, during the disturbance event.

The proportions in each row always sum to 1 to ensure conservation of carbon. The value entered in cell A is the proportion of above-ground biomass remaining after a disturbance (or 1 – fd) and the remainder is added to cells B and C in the case of fire, and B, C, and E in the case of harvest.

The Tier 1 assumption is that all of fd is emitted in the year of disturbance: therefore the value entered in cell F is fd.

Changes in Dead Organic Matter

EQUATION 2.17
ANNUAL CHANGE IN CARBON STOCKS IN DEAD ORGANIC MATTER

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

Where:

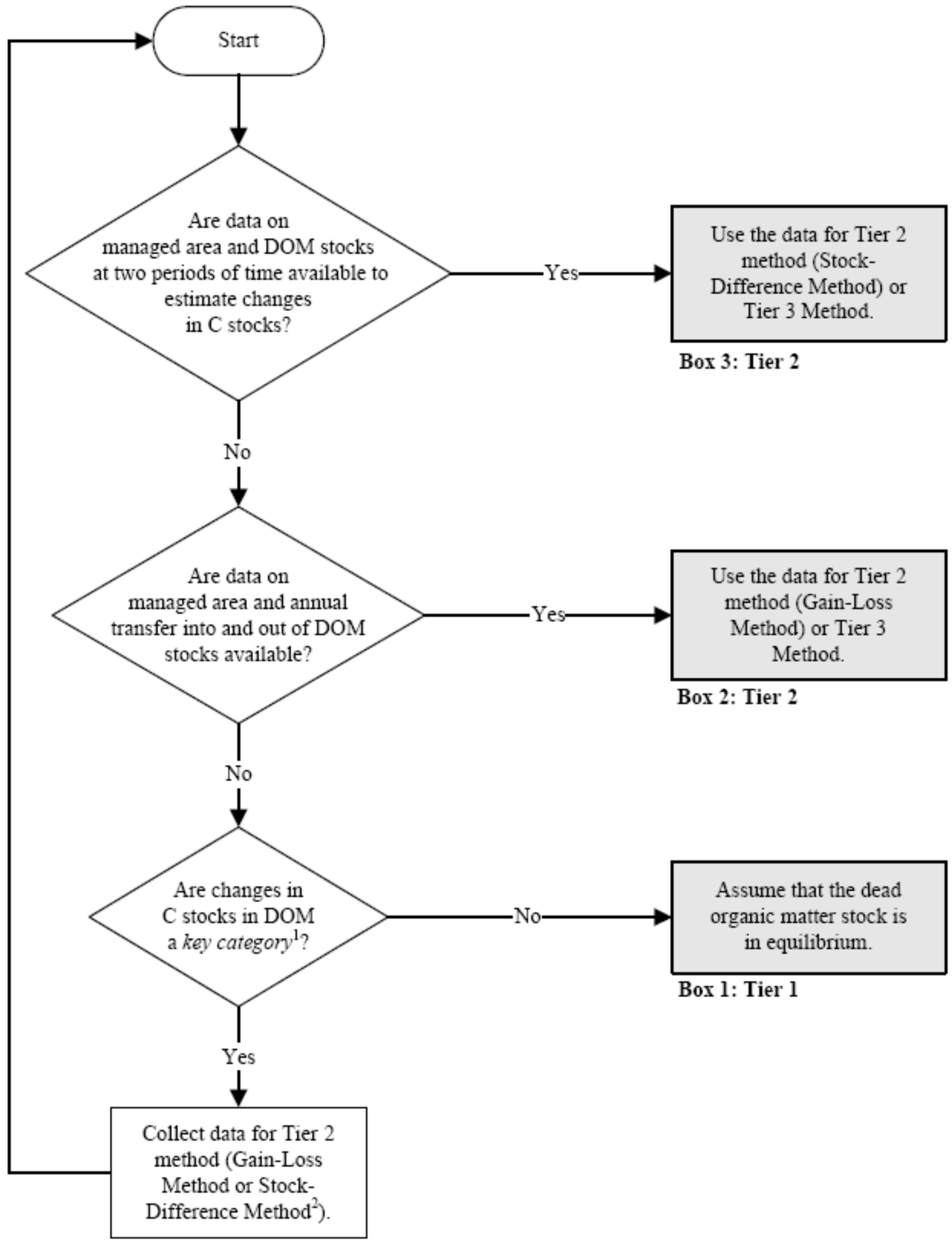
ΔC_{DOM} = annual change in carbon stocks in dead organic matter (includes dead wood and litter), tonnes C yr^{-1}

ΔC_{DW} = change in carbon stocks in dead wood, tonnes C yr^{-1}

ΔC_{LT} = change in carbon stocks in litter, tonnes C yr^{-1}

The Tier 1 assumption for both dead wood and litter pools for all land-use categories is that their stocks are not changing over time if the land remains within the same land-use category

Figure 2.3 **Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in dead organic matter for a land-use category**



Changes in Dead Organic Matter

EQUATION 2.18

ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD OR LITTER (GAIN-LOSS METHOD)

$$\Delta C_{DOM} = A \bullet \{(DOM_{in} - DOM_{out}) \bullet CF\}$$

Where:

ΔC_{DOM} = annual change in carbon stocks in the dead wood/litter pool, tonnes C yr^{-1}

A = area of managed land, ha

DOM_{in} = average annual transfer of biomass into the dead wood/litter pool due to annual processes and disturbances, tonnes d.m. ha^{-1} yr^{-1} (see next Section for further details).

DOM_{out} = average annual decay and disturbance carbon loss out of dead wood or litter pool, tonnes d.m. ha^{-1} yr^{-1}

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

Changes in Dead Organic Matter

EQUATION 2.19
ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD OR LITTER (STOCK-DIFFERENCE METHOD)

$$\Delta C_{DOM} = \left[A \bullet \frac{(DOM_{t_2} - DOM_{t_1})}{T} \right] \bullet CF$$

Where:

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter, tonnes C yr^{-1}

A = area of managed land, ha

DOM_{t1} = dead wood/litter stock at time t_1 for managed land, tonnes d.m. ha^{-1}

DOM_{t2} = dead wood/litter stock at time t_2 for managed 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 = 0.37 for litter), tonne C (tonne d.m.$)^{-1}$

Changes in Dead Organic Matter

EQUATION 2.20
ANNUAL CARBON IN BIOMASS TRANSFERRED TO DEAD ORGANIC MATTER

$$DOM_{in} = \{L_{mortality} + L_{slash} + (L_{disturbance} \bullet f_{BLol})\}$$

Where:

DOM_{in} = total carbon in biomass transferred to dead organic matter, tonnes C yr^{-1}

$L_{mortality}$ = annual biomass carbon transfer to DOM due to mortality, tonnes C yr^{-1} (See Equation 2.21)

L_{slash} = annual biomass carbon transfer to DOM as slash, tonnes C yr^{-1} (See Equations 2.22)

$L_{disturbances}$ = annual biomass carbon loss resulting from disturbances, tonnes C yr^{-1} (See Equation 2.14)

f_{BLol} = fraction of biomass left to decay on the ground (transferred to dead organic matter) from loss due to disturbance. As shown in Table 2.1, the disturbance losses from the biomass pool are partitioned into the fractions that are added to dead wood (cell B in Table 2.1) and to litter (cell C), are released to the atmosphere in the case of fire (cell F) and, if salvage follows the disturbance, transferred to HWP (cell E).

Note: If root biomass increments are counted in Equation 2.10, then root biomass losses must also be counted in Equations 2.20, and 2.22.

Changes in Dead Organic Matter

EQUATION 2.21

ANNUAL BIOMASS CARBON LOSS DUE TO MORTALITY

$$L_{mortality} = \sum (A \bullet G_W \bullet CF \bullet m)$$

Where:

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

A = area of land remaining in the same land use, ha

G_w = above-ground biomass growth, tonnes d.m. ha^{-1} yr^{-1} (see Equation 2.10)

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

m = mortality rate expressed as a fraction of above-ground biomass growth

Changes in Dead Organic Matter

EQUATION 2.22

ANNUAL CARBON TRANSFER TO SLASH

$$L_{slash} = [\{H \bullet BCEF_R \bullet (1+R)\} - \{H \bullet D\}] \bullet CF$$

Where:

L_{slash} = annual carbon transfer from above-ground biomass to slash, including dead roots, tonnes C yr^{-1}

H = annual wood harvest (wood or fuelwood removal), m^3 yr^{-1}

$BCEF_R$ = biomass conversion and expansion factors applicable to wood removals, which transform merchantable volume of wood removal into above-ground biomass removals, tonnes biomass removal (m^3 of removals)$^{-1}$. If $BCEF_R$ values are not available and if BEF and Density values are separately estimated then the following conversion can be used:

$$BCEF_R = BEF_R \bullet D$$

- D is basic wood density, tonnes d.m. m^{-3}
- Biomass Expansion Factors (BEF_R) expand merchantable wood removals to total aboveground biomass volume to account for non-merchantable components of the tree, stand and forest. BEF_R is dimensionless.

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)$^{-1}$. R must be set to zero if root biomass increment is not included in Equation 2.10 (Tier 1)

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

Fuelwood gathering that involves the removal of live tree parts does not generate any additional input of biomass to dead organic matter pools and is not further addressed here.

Changes in Dead Organic Matter

EQUATION 2.23

ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD AND LITTER DUE TO LAND CONVERSION

$$\Delta C_{DOM} = \frac{(C_n - C_o) \bullet A_{on}}{T_{on}}$$

Where:

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter, tonnes C yr^{-1}

C_o = dead wood/litter stock, under the old land-use category, tonnes C ha^{-1}

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha^{-1}

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses.

Changes in Dead Organic Matter

Inventories using a Tier 1 method assume that all carbon contained in biomass killed during a land-use conversion event (less harvested products that are removed) is emitted directly to the atmosphere and none is added to dead wood and litter pools.

Tier 1 methods also assume that dead wood and litter pool carbon losses occur entirely in the year of the transition.

The Tier 1 assumption is that DOM pools in non-forest land categories after the conversion are zero, i.e., they contain no carbon.

Changes in Soil Organic Matter

Soils are classified in order to apply reference C stocks and stock change factors for estimation of soil C stock changes, as well as the soil N_2O emissions (i.e., organic soils must be classified to estimate N_2O emissions following drainage). Organic soils are found in wetlands or have been drained and converted to other land-use types (e.g., Forest Land, Cropland, Grassland, Settlements). Organic soils are identified on the basis of criteria 1 and 2, or 1 and 3 listed below (FAO 1998):

1. Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm.
2. Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter).
3. Soils are subject to water saturation episodes and has either:
    a. At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or
    b. At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60% or more clay; or
    c. An intermediate, proportional amount of organic carbon for intermediate amounts of clay.

Changes in Soil Organic Matter

EQUATION 2.24

ANNUAL CHANGE IN CARBON STOCKS IN SOILS

$$\Delta C_{Soils} = \Delta C_{Mineral} - L_{Organic} + \Delta C_{Inorganic}$$

Where:

ΔC_{Soils} = annual change in carbon stocks in soils, tonnes C yr^{-1}

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

$L_{Organic}$ = annual loss of carbon from drained organic soils, tonnes C yr^{-1}

$\Delta C_{Inorganic}$ = annual change in inorganic carbon stocks from soils, tonnes C yr^{-1} (assumed to be 0 unless using a Tier 3 approach)

For Tier 1 and 2 methods, soil organic C stocks for mineral soils are computed to a default depth of 30 cm.

Changes in Soil Organic Matter

Mineral soils

For mineral soils, the default method is based on changes in soil C stocks over a finite period of time. The change is computed based on C stock after the management change relative to the carbon stock in a reference condition (i.e., native vegetation that is not degraded or improved). The following assumptions are made:

(i) Over time, soil organic C reaches a spatially-averaged, stable value specific to the soil, climate, land-use and management practices; and

(ii) Soil organic C stock changes during the transition to a new equilibrium SOC occurs in a linear fashion.

EQUATION 2.25
ANNUAL CHANGE IN ORGANIC CARBON STOCKS IN MINERAL SOILS

$$\Delta C_{Mineral} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$$SOC = \sum_{c,s,i} \left(SOC_{REF_{c,s,i}} \bullet F_{LU_{c,s,i}} \bullet F_{MG_{c,s,i}} \bullet F_{I_{c,s,i}} \bullet A_{c,s,i} \right)$$

(Note: T is used in place of D in this equation if T is ≥ 20 years, see note below)

Where:

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

SOC_0 = soil organic carbon stock in the last year of an inventory time period, tonnes C

$SOC_{(0-T)}$ = soil organic carbon stock at the beginning of the inventory time period, tonnes C

SOC_0 and $SOC_{(0-T)}$ are calculated using the SOC equation in the box where the reference carbon stocks and stock change factors are assigned according to the land-use and management activities and corresponding areas at each of the points in time (time = 0 and time = 0-T)

T = number of years over a single inventory time period, yr

D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, yr. Commonly 20 years, but depends on assumptions made in computing the factors F_{LU}, F_{MG} and F_I. If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years).

c = represents the climate zones, *s* the soil types, and *i* the set of management systems that are present in a country.

SOC_{REF} = the reference carbon stock, tonnes C ha^{-1} (Table 2.3)

F_{LU} = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless

[Note: F_{ND} is substituted for F_{LU} in forest soil C calculation to estimate the influence of natural disturbance regimes.

F_{MG} = stock change factor for management regime, dimensionless

F_I = stock change factor for input of organic matter, dimensionless

A = land area of the stratum being estimated, ha. All land in the stratum should have common biophysical conditions (i.e., climate and soil type) and management history over the inventory time period to be treated together for analytical purposes.

Figure 2.4 **Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in mineral soils by land-use category**

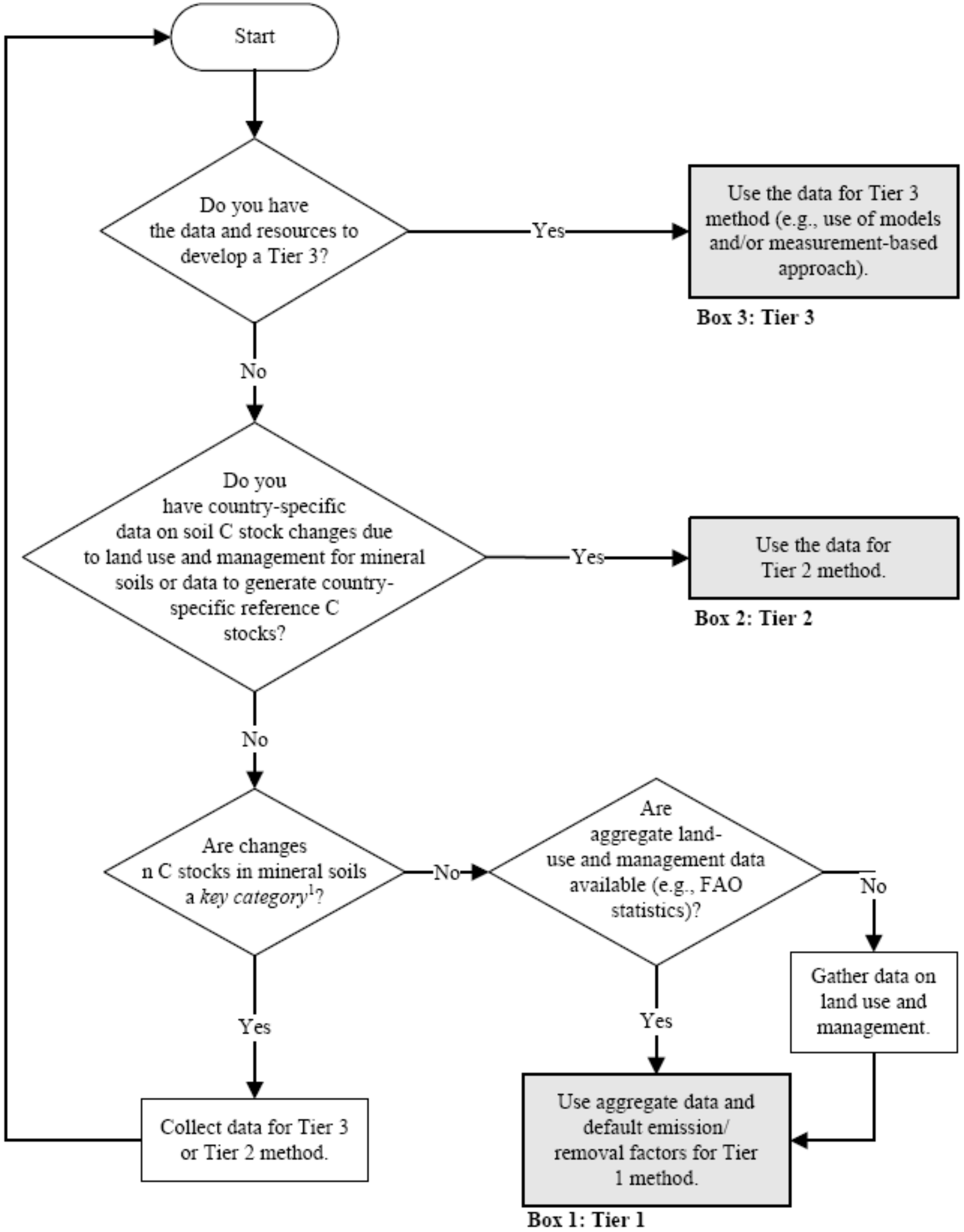
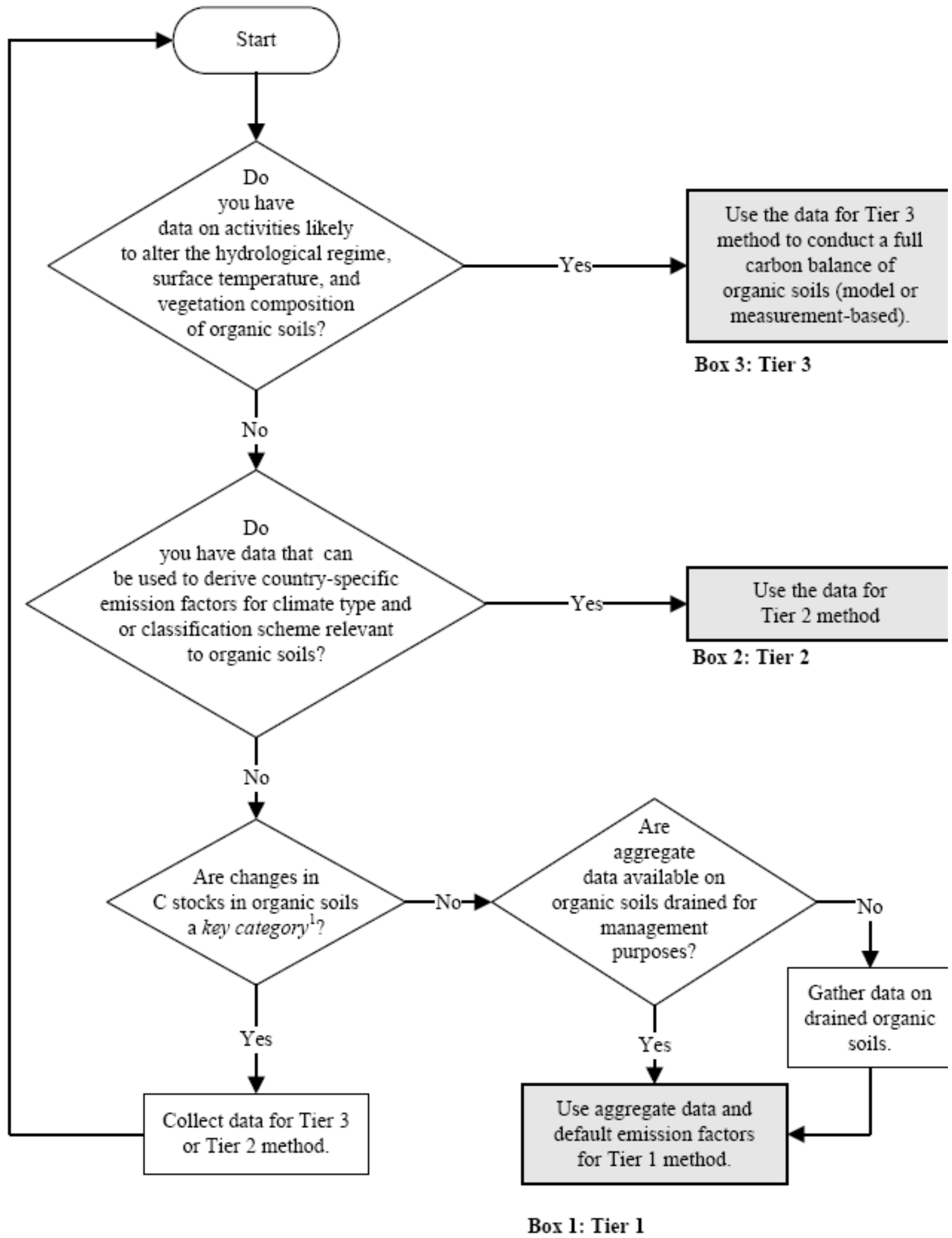


Figure 2.5 **Generic decision tree for identification of appropriate tier to estimate changes in carbon stocks in organic soils by land-use category**



Changes in Soil Organic Matter

EQUATION 2.26

ANNUAL CARBON LOSS FROM DRAINED ORGANIC SOILS (CO_2)

$$L_{Organic} = \sum_{c} (A \bullet EF)_c$$

Where:

$L_{Organic}$ = annual carbon loss from drained organic soils, tonnes C yr^{-1}

A = land area of drained organic soils in climate type *c*, ha

Note: A is the same area (F_{os}) used to estimate N_2O emissions in Chapter 11, Equations 11.1 and 11.2

EF = emission factor for climate type *c*, tonnes C ha^{-1} yr^{-1}

Regional workshop: “Capacity Development for Sustainable National Greenhouse Gas Inventories – AFOLU sector (CD-REDD II) Programme

Thank for your attention

Quito, Ecuador *10-13 May 2011*