CHAPTER 8

SETTLEMENTS

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This section provides updates and elaboration on methods.

Few allometric biomass equations exist specifically for trees or shrubs in urban settings (Nowak, 1996; Jo, 2002;) so investigators have tended to apply equations derived for forest trees, adjusting the resulting biomass with a coefficient (such as 0.80 [Nowak, 1994; Nowak and Crane, 2002; Nowak et al., 2013]) intended to take account of the allometry of open-grown trees in cities where above-ground biomass for a given diameter is typically lower than that of forest-grown trees (Nowak, 1996). Allometric equations for some shrub species exist, but have not routinely been applied to urban settings (Smith and Brand, 1983; Nowak *et al*., 2002 for shrub leaf biomass estimates). Below-ground tree biomass can be derived from above-ground biomass by multiplying the latter by an estimated root: shoot ratio, as described by Cairns *et al*. (1997) and applied for urban settings by Nowak *et al*. (2002). See Chapter 4 (Forest Land) for examples of root: shoot ratios (R) (also called below-ground to above-ground biomass ratio) often used in forest settings. Ratios appropriate to the region of interest can be assumed to apply without modification to settlements.

Biological tree growth and mortality in settlements can be affected by urban conditions such as variations in local air quality, atmospheric deposition, enhanced atmospheric CO2 concentrations, and reduced air exchange in the root zone due to impermeable paving surfaces (e.g., Pouyat et al., 1995; Idso et al., 1998; Idso et al., 2001; Gregg et al., 2003; Pouyat and Carreiro, 2003; Nowak et al., 2013). In addition, management practices for urban trees also affect its growth and mortality. Therefore, the values and equations used to predict tree growth in settlements at higher tiers should, to the extent feasible, allow for the surrounding environment and the condition of the trees, and take into account management type.

Carbon stored in the woody components of trees makes up the largest compartment of standing biomass stocks and annual biomass increment in settlements. Data are still sparse, though availability is increasing. For example, Nowak and Crane (2002) estimated on a citywide basis that the net annual carbon storage by trees in cities in the conterminous USA ranged from 600 to 32,200 tonnes C yr^{-1}. Jo (2002) found that the amount of C sequestered annually in three Korean cities varied from 2,900 to 40,300 tonnes. At a city level, the amount of C sequestered by trees in Canberra were estimated 6,000 tonnes C yr^{-1} (Brack, 2002) and 5,400 tonnes C yr^{-1} in Barcelona (Chaparro and Terradas, 2009) Clearly, the estimates depend on the definition and hence extent of the settlement areas being considered.

The variation is less per unit land area; for ten cities in the United States, measurements of C stored in woody biomass ranged from 150 to 940 kg C ha^{-1} yr^{-1} (Nowak and Crane, 2002) and for three Korean cities annual C stored in woody biomass varied from 530 to 800 kg C ha^{-1} yr^{-1} (Jo, 2002). Trees in urban lawns in Colorado (USA) stored 1,590 kg C ha^{-1} yr^{-1} (Kaye *et al*., 2005). Nowak and Crane (2002) found that annual sequestration rates ranged from 0.12 to 0.26 kg C m^{-2} crown cover yr^{-1}, while Brack (2002) used a model to estimate that annual sequestration in Canberra between 2008 and 2012 would be 0.27 kg C m^{-2} yr^{-1}. The studies indicate that annual sequestration per unit of area in settlements depends on specific situation on urban land such as type of vegetation, species composition, density of planted tree and shrub, management type of urban area and etc..

Tier 1

This method assumes, probably conservatively, that changes in biomass carbon stocks due to growth in biomass are fully offset by decreases in carbon stocks due to removals (i.e., by harvest, pruning, clipping) from both living and from dead biomass (e.g., fuelwood, broken branches, etc.). Therefore, in a Tier 1 approach $\Delta C_G = \Delta C_L$ and for all plant components, and $\Delta C_B = 0$ in Equation 2.7.

Tier 2

Trees

Tier 2 calls for parameter values for CRW_{ij} (Equation 8.2) and C_{ij} (Equation 8.3). In *the 2006 IPCC guidelines,* it was explained that a default removal factor for tree biomass (CRW) of 2.9 tonnes C (ha crown cover)$^{-1}$ yr $^{-1}$ is usually suitable for Tier 2a (see Table 8.1). This estimate is based on a sample of ten US cities, with values that ranged from 1.8 to 3.4 tonnes C (ha crown cover)$^{-1}$ yr^{-1} (Nowak and Crane, 2002). The updated study on 28 US cities and 6 US state provided an average removal factor for tree biomass (CRW) of 2.8 tonnes C (ha crown cover)$^{-1}$ yr $^{-1}$ which was standardized to 153 frost-free days (Nowak et al., 2013). As there is no significant change observed in the updated studies, 2.9 tonnes C (ha crown crown cover)$^{-1}$ yr $^{-1}$ is still treated as a global default. Updated table 8.1 shows updated data and the range of default CRW_{ij} [*the updated table will be provided in the SOD*]. Values appropriate to national circumstances can also be developed.

Using Tier 2b, the removal factor is C_{ij}. Updated Table 8.2 provides defaults carbon accumulation rates for tree species classes for use at Tier 2b. [*the updated table will be provided in the SOD*] [These estimates are based on various allometric equations and limited field data from urban areas in the USA, and are averages for trees of all sizes (not just mature trees). (*to be assessed based on the final version of the Table 8.2*)] Tiers 2a and 2b methods provide biomass estimates for total combined above-ground and below-ground woody biomass. Additional explanation may be needed around here about new default parameters for Tier 2b. If required below-ground biomass can be estimated separately using a root: shoot ratio of 0.26 (Nowak *et al*., 2002). If trees in settlements are subject to similar or same management implemented in forest land, the updated root: shoot ratio of relevant category in Table 4.4 in chapter 4 (forest land) may also be applied.

For Tiers 2a and 2b, the default assumption for ΔC_L where the average age of the tree population is less than or equal to 20 years is zero. This is based on the assumption that urban trees are net sinks for carbon when they are actively growing and that the active growing period (AGP) is roughly 20 years, depending on tree species, planting density, and location. Thereafter, the method assumes that the accumulation of carbon in biomass slows with age, and thus for trees older than the AGP, increases in biomass carbon are assumed to be offset by losses from pruning and mortality. For trees older than the AGP this is conservatively accounted for by setting $\Delta C_{G_{wood}} = \Delta C_{L_{wood}}$. Countries can define AGP depending on their circumstances.

When homestead garden and/or horticulture land are allocated in settlements based on its national land use classification, countries may apply the default carbon accumulation ratio and the estimation method of homestead garden and/or horticulture provided in chapter 5) of the 2019 Refinement.

Other woody perennial types

Countries may, for any perennial type, develop their own values for CRW_{ij} (in Equation 8.2) and C_{ij} (in Equation 8.3). A conservative assumption of no change in any of these components (i.e., $CRW_{ij} = 0$ and $C_{ij} = 0$) can also be applied.

Herbaceous biomass

Tiers 2a and 2b both assume no change in herbaceous biomass in *settlements remaining settlements*. Using this method, $\Delta C_{G_{Herbs}} = \Delta C_{L_{Herbs}}$ and ΔC_B is based on the difference between increment and losses in woody biomass only.

Tier 3

For Tier 3, countries should develop plant type-specific biomass increment factors appropriate to national circumstances. Country-specific parameters and growth equations should be based on the dominant climate zones and particular species composition of the major settlements areas in a country, before making estimates for less extensive settlements. If country-specific biomass increment parameters are developed from estimates of biomass on a dry matter basis, they need conversion to units of carbon using either a default carbon fraction (CF) of 0.5 tonne C (tonne d.m.)$^{-1}$ or a carbon fraction that is more appropriate to circumstances, including application of carbon fraction values in Table 4.3 in chapter 4 (Forest land).

Under higher tiers, the assumptions for ΔCL should be evaluated and modified to address national circumstances better. For instance, countries may have information on age-dependent and/ or species-specific carbon losses in settlement trees. In this case, countries should develop a loss term and document the resources and rationale used in its development. Instead of developing a country specific loss term, countries may use country specific active growing period (AGP) other than 20 years as an alternative way. In this case, it is good practice to use urban green type specific AGP based on detailed categorisation of urban green area. This is because management of urban trees are not implemented uniformed way, and carbon accumulation ratio and growing years depend on management type of urban trees/urban green area, such as street trees, trees in urban park without frequent pruning and/or urban green area treated as more natural state (Nowak et al. 2013; Chaparro and Terradas, 2009; Jo, 2002).

When countries consider applying other countries data for their estimation, it is good practice to examine similarity of climatic conditions, urban structures and/or type of planted trees to the other countries situation, and also consider the data can be used directly or used with some adjustment.

If a country adopts the stock-difference method (Equation 2.8) and/or applying National Forest Inventory for urban trees, it should have representative sampling and periodic measurement system to estimate the changes in biomass carbon stocks.

[Placeholder]:

Updated Table 8.1 and Table 8.2 are under the preparation and to be provided in the second order draft.

The updated tables potentially provide new default values with possibly information on countries or regions to be applied and (uncertainty,) taking into account new studies including Nowak et al. 2013; Chaparro and Terradas, 2009; Davies et al., 2011; Strohbach and Haase, 2012; Mills, G. et. al. 2015 and some countries reports (ex. Japan, USA)]

Updated- Table 8. 1 Tier 2A default crown cover area-based growth rates (CRW) for urban tree crown cover by region

Region	**Default annual carbon accumulation per ha tree crown cover [tonnes C (ha crown cover)$^{-1}$ yr^{-1}]**	**Range**	**Source**
United States (global default)	2.9	tbc	a
United States – updated	2.8	tbc	b
Australia	3.6	tbc	c
Tbc			
[a] Nowak and Crane 2002; average of 10 US cities. [b] Nowak et al. 2013; average of 28 US cities and 6 US state [c] Brack 2002; modelling analysis in Canberra.			

Updated-8. 2 Tier 2B Default average annual carbon accumulation per tree in urban trees by species classes				
Region	**Broad species class**	**Default annual carbon accumulation per tree(tonnes C yr^{-1})**	**Range**	**Sources**
tbd	Aspen	0.0096	tbd	a
	Soft maple	0.0118	tbd	a
	Mixed hardwood	0.0100	tbd	a
	Hard maple	0.0142	tbd	a
	Juniper	0.0033	tbd	a
	Cedar/larch	0.0072	tbd	a
	Douglas fir	0.0122	tbd	a
	True fir/Hemlock	0.0104	tbd	a
	Pine	0.0087	tbd	a
	Spruce	0.0092	tbd	a
		X		

[a] D. Nowak (2002; personal communication)

8.2.1.3 CHOICE OF ACTIVITY DATA

No Refinement

8.2.1.4 UNCERTAINTY ASSESSMENT

No Refinement

[Placeholder]:

New information may be added after completion of updated Tables 8.1 and 8.2]

8.2.2 Dead Organic Matter

No Refinement

8.2.3 Soil Carbon

No Refinement

Soils in settlements may be sources or sinks of CO_2 depending on previous land use, soil burial or collection during development, and current management, particularly with respect to nutrient and water applications in addition to the type and amount of vegetation cover interspersed among roads, buildings and associated infrastructure (Goldman *et al*., 1995; Pouyat *et al*., 2002; Jo, 2002; Qian and Follett, 2002; Kaye *et al*., 2004). Only a few studies have been conducted at the time of writing that evaluate the effect of settlement management on soil C, and most of the focus has been on North America (e.g., Pouyat *et al*., 2002), making it difficult to generalize. For example, there are likely to be large differences that have not been well studied between settlements in developed countries and developing countries.

Estimating the impact of settlement management on soil C storage will be particularly important in countries with a large portion of land in cities and towns, or high rates of settlement expansion. For mineral soils, the impact of settlement land use and management on soil C stocks can be estimated based on differences in storage among settlement management classes relative to a reference condition, such as other managed land uses, or native lands. Settlement management classes could include turf grass (e.g., lawns and golf courses), urban woodlands, gardens, refuse areas (e.g., garbage dumps), barren areas (exposed soil), and infrastructure (e.g., roadways, houses, and buildings). Although organic soils are less commonly used for settlement development, C is emitted from these soils if they are drained due to enhanced decomposition, similar to the effect of drainage for agricultural purposes (Armentano and Menges, 1986).

General information and guidelines for estimating changes in soil C stocks are found in Chapter 2, Section 2.3.3, and should be reviewed before proceeding with specific guidelines dealing with settlements. The total change in soil C stocks for settlements is computed using Equation 2.24 in Chapter 2, which combines the change in soil organic C stocks for mineral soils and organic soils; and stock changes for soil inorganic C pools (Tier 3 only). The next section provides specific guidance on estimating the soil organic C stock change in settlements. For general discussion on soil inorganic C, no additional information is provided in the settlements discussion below.

To account for changes in soil C stocks associated with *Settlements Remaining Settlements*, countries need to have estimates of the relevant settlement area, stratified by climate region and soil type. More detailed inventory estimations can be made through ground-based surveys and/or periodic analyses of remote sensing imagery to determine settlement management classes (e.g., turf grass, urban woodlands, gardens, refuse areas, barren areas and infrastructure).

Inventories can be developed using Tier 1, 2 or 3 approaches, with Tier 3 requiring more detail and resources. It is also possible that countries will use different tiers to prepare estimates for the separate components in this source category, which includes mineral soils and organic soils in addition to soil inorganic C pools, if using a Tier 3 approach. Figures 2.4 and 2.5 in Chapter 2 are decision trees that provide guidance for identification of appropriate tier to estimate changes in carbon stocks in mineral soils and organic soils, respectively.

8.2.3.1 CHOICE OF METHOD

This section has further elaboration on methods and provides new guidance.

Mineral soils

Tier 1

It is assumed in the Tier 1 method that inputs equal outputs so that settlement soil C stocks do not change in *Settlements Remaining Settlements*.

Tier 2

Refining Application of Default Equations

The Tier 2 approach for mineral soils uses Equation 2.25 in Chapter 2; involves country- or region-specific reference C stocks and/or stock change factors and possibly suitably disaggregated land-use activity and environmental data.

Three-Pool Steady-State C Model

The three-pool steady-state soil C model is based on estimating C inputs to soils and applying soil carbon pool specific decomposition rates that are modified by given environmental conditions and management practices. This model embraces more of the heterogeneity in soils, by subdividing soil C pool into different rates of turnover, i.e., fast (Active Pool), intermediate (Slow Pool) , and long turnover times (Passive Pool).

Tier 3

Tier 3 is an advanced method for estimating soil C stocks associated with settlement cover classes, such as a dynamic model or measurement/monitoring network. Few if any models or measurement systems have been developed for estimating soil C stocks in settlements that would be considered a Tier 3 method. This should be considered if settlement soil C is a key source category. Additional guidance on Tier 3 approaches is given in Chapter 2, Section 2.3.3

Organic soils

No refinement, See 2013 Wetlands Supplement

8.2.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTORS

This section has further elaboration on methods and provides new guidance.

Mineral soils

Tier 1

It is assumed in the Tier 1 method that inputs equal outputs so that settlement soil C stocks do not change in *Settlements Remaining Settlements.*

Tier 2

Refining Application of Default Equations

Tier 2 requires estimation of country-specific stock change factors. Equation 2.25 in Chapter 2 uses three levels of stock change factor depending on the land use, the management within the land use, and the level of inputs. The inventory compiler should define management classes relevant to settlements (such as turf grass), and derive stock change factors for land use (F_{LU}) based on the C storage for each class relative to the reference condition which is likely to be native lands. Management factors (F_{MG}) give flexibility to specify the way land use is managed (such as for sports fields or ornamental use) and input factors (F_I) can be used to represent the influence of management on C of input such as watering or fertilization practices.

The depth for evaluating soil C stock changes can also be extended with the Tier 2 method. This will require extending the depth of the reference C stocks (SOCref) and stock change factors for all land uses (i.e., FLU, FI, and FMG) to ensure consistency. Variable depths between reference stocks and stock change factors are likely to introduce biases into the inventory estimates that are computed using Equation 2.25.

Three-Pool Steady-State C Model

Default parameters are provided for the three-pool steady-state C pool equations (Chapter 2, Section 2.3.3.1, Table 2), but parameters may be revised if experimental data are available to test the model.

Tier 3

Tier 3 requires some combination of detailed process models and data gathering, with a sampling strategy and periodic re-sampling, to capture land-use and management effects. See Chapter 2, Section 2.3.3.1 for further discussion.

Organic soils

No Refinement, See 2013 Wetlands Supplement

8.2.3.3 CHOICE OF ACTIVITY DATA

This section has further elaboration on methods and provides new guidance.

Mineral soils

Tier 1

It is assumed in the Tier 1 method that inputs equal outputs so that settlement soil C stocks do not change in *Settlements Remaining Settlements*.

Tier 2

Refining Application of Default Equations

For the Tier 2 level, activity data consist of areas for settlements subdivided by climate, soil type, and /or management classes, as needed, to correspond with the stock change factors described above. Municipality records may be useful for determining the proportion of various management classes (e.g., shopping areas, subdivisions, businesses, parks, schools, etc.), augmented with knowledge of country experts about the approximate distribution of settlement classes (i.e., turf grass, urban woodlands, gardens, refuse areas, barren areas and infrastructure). Tier 2 approaches may involve a finer stratification of environmental data, including climate regions and soil types, provided the corresponding stock change factors have been developed.

Three-Pool Steady-State C Model

This method requires soil C input data based on the amount of biomass that is converted to dead organic matter annually. This rate will vary depending on the settlement management class and other environmental variables. Removals or reductions in dead organic matter are subtracted from the C input amount, which could occur with turfgrass management, tree pruning, and other management activities in settlements. Beyond the amount of C input, the average lignin and nitrogen contents of the new dead organic matter are also required to estimate the size of the three C pools.

Tier 3

The activity data for application of dynamic models and/or a direct measurement-based inventory will characterise climate, soil, topographic and management regime, depending on the model or sampling design.

Organic soils

No refinement, See 2013 Wetlands Supplement

8.2.3.4 UNCERTAINTY ASSESSMENT

No Refinement

8.3 LAND CONVERTED TO SETTLEMENTS

8.3.1 Biomass

8.3.1.1 CHOICE OF METHOD

This section provides elaboration on methods.

The general approach for calculating the immediate change in live biomass accruing from the conversion to Settlements is represented by Equations 2.15 and 2.16 in Chapter 2. The mean annual biomass increment resulting from the transition is represented by the difference between the biomass in the settlement land-use category immediately after the transition (B_{After}) and the biomass in the previous category (B_{Before}).

This method follows the approach in the *Guidelines* for other land-use transitions: the annual change in carbon stock in biomass due to land conversion is estimated (using Equation 2.16) by multiplying the area converted annually to settlements by the difference in carbon stocks between biomass in the system prior to conversion (B_{Before}) and that in the settlements after conversion (B_{After}).

In the higher tiers, it is necessary to add growth during the year of inventory (ΔCG) and subtract loss (ΔCL) to obtain the net change in carbon stocks on land converted to Settlements (Equation 2.15). It should be noted that growing periods of trees, other perennial woody biomass and herbaceous biomass are different. For example, of the default assumption in other chapter and sectors, the growing periods is 20 years for tree biomass in settlements remaining settlements (Tier 2, see section 8.2.1) and land converted to grassland achieve their steady-state of biomass during the first year following the conversion (Tier 1 see section 6.3.1.1). There is no default for shrub. When estimate ΔCG, it is good practice to reflect the difference of the growing period and/or carbon density under steady-state for each biomass type.

Tier 1

For Tier 1, in the initial year following conversion to the settlement land use, the most conservative approach is to set B_{After} to zero, meaning that the process of development of settlements causes carbon stocks to be entirely depleted. Under Tier 1, growth during the year of inventory (ΔC_G) and subtract loss (ΔC_L) are not necessary to estimate since this estimation only covered in Equation 2.16 (for Tier 2) and also this carbon stock change is not estimated under Tier 1 in *settlements remaining settlements*. This is the consistent approach explained in “Step by step method for implementation” in page 8.19 of chapter 8, volume 4 of the 2006 IPCC guidelines.

When potential gains of carbon are expected in land converted to settlements and information on green space area or number of tree in land converted to settlements is available, country can apply the default method of Tier 2 in *settlements remaining settlements* for estimating ΔC_G and ΔC_L even in Tier 1.

Tier 2

At Tier 2, country-specific carbon stocks can be applied to activity data disaggregated to a level of detail adapted to national circumstances for the estimation of B_{Before}. At the higher tiers, the area of each land-use or land cover type converted to another type in a settlement (examples of land use and land cover types are described in Section 8.2) should be recorded, because that area is associated with the amount of carbon both before and after the conversion. Settlement land-use or land cover types are likely to differ in carbon density. For estimations of ΔC_G and ΔC_L, country can be use country specific factors. Alternatively default estimation consistent with Tier 2 in *settlements remaining settlements* are also possible to be applied. For both case, the information on on green space area or number of tree in land converted to settlements is necessary for estimation.

Tier 3

At Tier 3, countries can use the stock difference method (Equation 2.8) or other advanced estimation methods that may involve complex models and highly disaggregated activity data including, if available, more detailed information about B_{After} on a country- or biome-specific basis. The method using National Forest Inventory is also covered by Tier.3. In this case, country should also take into account the guidance of chapter 4 (forest land) as appropriate.

8.3.1.2 CHOICE OF EMISSION/REMOVAL FACTORS

This section refines guidance by updating Table 8.4 and explanation of Tier 2 and Tier 3 guidance. The updated Table 8.4 provides more complete information on how to use B_{Before} and suggesting using consistent factors used in other chapters’ default assumption. The guidance on Tier 2 and Tier 3 are enhanced to clarify how to choice and use emission/removal factors under higher tiers.

Tier 1

Tier 1 methods require estimates of the biomass of the land use before conversion and after conversion. It is assumed that all biomass is cleared when preparing a site for settlements, thus, the default for biomass immediately after conversion is 0 tonnes ha^{-1}. Updated Table 8.4 provides default values for biomass before conversion (B_{Before}).

Table 8. 3 Text will be provided for the SOD.

Updated Table 8. 4 default biomass carbon stocks removed due to land conversion to settlements

Land-use category	Carbon stock in biomass before conversion (B_{Before}) (tonnes C ha^{-1})	Error range #
Forest Land	See Chapter 4, Tables 4.7 to 4.12 for carbon stocks in a range of forest types by climate regions. Stocks are in terms of dry matter. Multiply values by a carbon fraction (CF) in Table 4.3 consistent with what used in forest land estimation to convert dry matter to carbon.	See Section 4.3 (Land Converted to Forest Land)
Grassland	See Table 6.4, Chapter 6 for carbon stocks in a range of grassland types by climate regions. Multiply default carbon fraction (CF) 0.47 (for herbaceous biomass for Grassland, see page 6.29, Chapter 6) to convert dry matter to carbon.	± 75% *[This range may change based on updated Table 6.4]*
Cropland	For cropland containing annual crops: Use default of 4.7 tonnes of carbon ha^{-1} or 10 tonnes of dry matter ha^{-1} (see Chapter 6, Section 6.3.1.2). For cropland containing perennial crop: Use carbon stocks in Updated Table 5.9 as appropriate.	± 75% *[This range may change based on updated Table 5.9]*

Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean.

Tiers 2

Tier 2 methods replace the default data by country-specific data for B_{Before}. For calculation of ΔC_G and ΔC_L, country may use country-specific data. The default factors of Tier 2 in *settlement remaining settlements* may also be used when country-specific data is not available. In this case, countries should follow the guidance on either Tier 2A or Tier 2B in Section 8.2.1, *Settlements Remaining Settlements*, i.e. using the default annual carbon accumulation ratio provided in Table 8.1 or Table 8.2 for ΔC_G and ΔC_L can be zero noting that all land converted to settlements are within the duration of the default AGP (=20 years).

Tiers 3

Tier 3 involves detailed modelling or measurement data relevant to the conversion processes. Country may use average biomass stocks data for greenspace in settlements instead of using carbon accumulation ratio in its estimation. In this case, it may take more than one year to reach the average biomass stocks following land conversion. Countries should consider the appropriate activity data to reflect the years to reach the average biomass stocks in its estimation. When countries estimate account annual carbon accumulation occurred by establishing trees, shrubs or herbaceous biomass differently, this case also need consideration of growing years in each biomass type. Each removal factor should be multiplied by the appropriate activity data, i.e areas under growing years in each biomass.

8.3.1.3 CHOICE OF ACTIVITY DATA

This section provides an elaboration on methods.

Activity data for estimating changes in biomass on land areas converted to Settlements can be obtained, consistent with the general principles set out in Chapter 3, through national statistics, from forest services, conservation agencies, municipalities, survey and mapping agencies. Cross-checks should be made to ensure complete and consistent representation of annually converted lands in order to avoid possible omissions or double counting. Data should be disaggregated according to the general climatic categories and settlements types. For Tier.2 and Tier 3, data related to green covered area, in land areas converted to Settlements is necessary. Tier 3 inventories will require more comprehensive information on the establishment of new settlements, with refined soil classes, climates, and spatial and temporal resolution. All changes having occurred over the number of years selected as the transition period should be included with transitions older than the transition period (default 20 years) reported as a subdivision of *Settlements Remaining Settlements*.

Higher tiers require greater detail but the minimum requirement for inventories to be consistent with the IPCC Guidelines is that the areas of Forest Land conversion can be identified separately. This is because forest will usually have higher carbon density before conversion. This implies that at least partial knowledge of the land-use change matrix, and therefore, where Approaches 1 and 2 from Chapter 3 are used to estimate land area, supplementary surveys may be needed to identify the area of land being converted from Forest Land to Settlements. As pointed out in Chapter 3, where surveys are being set up, it will often be more accurate to seek to establish directly, areas undergoing conversion, than to estimate these from the differences in total land areas under particular uses at different times.

Step by step method for implementation

Tier 1

Use default values for Bbefore from respective land-use category chapter (Forest Land, Grassland, etc) and assume that BAfter equals zero in Equation 2.16.

Step 1: Apply Equation 2.16 to each land-use type converted to settlement lands;

Step 2: Add up the biomass changes over all the land-use types; and

Step 3: Multiply the result by 44/12 to obtain the amount of CO2 equivalents emitted (the sum obtained in Step 2 will be a negative number) from the land conversion.

Tier 2

The typical steps to implement a Tier 2 method (the case of using the default assumption for ΔCG and ΔCL) are:

Step 1: Use the methods described in Chapter 3, including where relevant cadastral and planning records or the analysis of remote sensing images (or both), to estimate the change in area between the present and the last area survey.

Step 2: Define — as a first approximation — settlement land-use types on the basis of the proportion of greenspace. For instance, three tentative land-use classes could be: Low (less than 33% greenspace), Medium (from 33 to less than 66% greenspace), and High (more than 66% greenspace). Each one of those classes can be assigned with an average carbon content, obtained from the species surveyed in similarly defined classes for accounting biomass changes in Section 8.2.

Step 3: Draw a land-use conversion area matrix for the land-use transitions defined in Step 2.

Step 4: Estimate with equations the biomass stocks of the defined land-use types and the converted land-use types (to obtain BBefore and BAfter), apply Equation 2.16 to each non-empty cell of the land-use change matrix, add up the changes in carbon stocks, and multiply the sum by 44/12 to obtain the emission/removal of CO2 equivalents.

Step 5: Calculate ΔCG, using either Method A or Method B in Section 8.2.1, Settlements Remaining Settlements (the choice of method will depend on the applicability of the emission and removal factors, as well as the availability of activity data). This will be used in Equation 2.15.

Step 6: Calculate ΔCL, using Methods as described in Section 8.2.1.3, Settlements Remaining Settlements.

Step 7: Calculate the change in carbon stocks in live biomass resulting from the land-use transition to Settlements, accounting for the biomass increment, biomass losses, and biomass change due to land-use conversion as given in Equation 2.15.

8.3.1.4 UNCERTAINTY ASSESSMENT

No Refinement

8.3.2 Dead organic matter

No Refinement

8.3.3 Soil carbon

No Refinement

Land conversion to Settlements occurs with development and expansion of cities and towns on former Forest Land, Cropland, Grassland, Wetlands, and Other Land. These conversions change soil C stocks due to mechanical disturbance of the soil; soil burial or collection during development; type and amount of vegetated cover; in addition to the new management regime, particularly with respect to nutrient and water applications.

General information and guidelines for estimating changes in soil C stocks are found in Chapter 2, Section 2.3.3 (including equations). The total change in soil C stocks for Land Converted to Settlements is computed using Equation 2.24, which combines the change in soil organic C stocks for mineral soils and organic soils; and stock changes associated with soil inorganic C pools (for Tier 3 only).

To account for changes in soil C stocks associated with land converted to Settlements, countries need to have estimates of the areas of land converted to Settlements during the inventory time period, stratified by climate region and soil type. If aggregate land-use data are used and specific conversions among uses are not known, soil organic C (SOC) stock changes can still be computed using the methods provided in *Settlements Remaining Settlements*, but the land-base area will then probably be different for settlements in the current year relative to the initial year in the inventory, and the dynamics of the transition will be less well represented. Chapter 3 (Consistent representation of lands) emphasises the importance of maintaining consistency in total land area.

8.3.3.1 8.3.3.1 CHOICE OF METHOD

This section has further elaboration on methods, and provides new guidance.

Inventories can be developed using Tier 1, 2 or 3 approaches, with each successive Tier requiring more detail and resources than the previous one. It is also possible that countries may use different tiers to prepare estimates for the separate sub-categories of soil C (i.e., soil organic C stocks changes in mineral soils and organic soils, and stock changes associated with soil inorganic C pools, are estimated at Tier 3). Decision trees are provided for mineral soils (Figure 2.4) and organic soils (Figure 2.5) in Section 2.3.3.1 (Chapter 2) to help selection of the appropriate tiers.

Mineral soils

Tier 1

Change in soil organic C stocks can be estimated for mineral soils with land-use conversion to Settlements using Equation 2.25 in Chapter 2. For Tier 1, the initial (pre-conversion) soil organic C stock ($SOC_{(0-T)}$) and C stock in the last year of the inventory time period (SOC_0) are determined from the common set of reference soil organic C stocks (SOC_{REF}) and default stock change factors (F_{LU}, F_{MG}, F_I). Areas of exposed bedrock in Forest Land or the previous land use are not included in the soil C stock calculation (assume a stock of 0). Annual rates of emissions (source) or removals (sink) are calculated as the difference in stocks (over time) divided by the time dependence (D) of the stock change factors (default is 20 years).

Tier 2

Refining Application of Default Equations

The Tier 2 approach for mineral soils also uses Equation 2.25 in Chapter 2, but involves country- or region-specific reference C stocks and/or stock change factors, and possibly a more disaggregated classification of land-use activity and environmental data. Removal, translocation or burial of soil C during development is a particular issue for settlements. To the extent that soil C is not decomposed during the development phase and resides deeper in the profile, is translocated to another area, or possibly used as a commodity. It is *good practice* for Tier 2 stock change factor to be adjusted to reflect the reduction in loss of C to the atmosphere as CO_2.

Three-Pool Steady-State C Model

The three-pool steady-state soil C model is based on estimating C inputs to soils and applying soil carbon pool specific decomposition rates that are modified given environmental conditions and management practices. This model embraces more of the heterogeneity in soils, by subdividing soil C pool into different rates of turnover, i.e., fast (Active Pool), intermediate (Slow Pool), and long turnover times (Passive Pool).

Tier 3

Tier 3 methods will involve more detailed and country-specific models and/or measurement-based approaches along with highly disaggregated land-use and management data. It is *good practice* that Tier 3 approaches for estimating soil C change from land-use conversions to Settlements, employ models, data sets and/or monitoring networks that are capable of representing transitions over time from other land uses, including Forest Land, Grassland, Cropland or other lands. Tier 3 methods need to be integrated with estimates of biomass removal and the post-clearance treatment of plant residues (including woody debris and litter), as variation in the removal and treatment of residues (e.g., burning, site preparation) will affect C inputs to soil organic matter formation and C losses through decomposition and combustion. Models should be validated with independent observations from country- or region-specific field locations that are representative of the interactions of climate, soil and management on post-conversion change in soil C stocks.

Organic soils

No Refinement, See 2013 Wetlands Supplement

8.3.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTOR

This section has further elaboration on methods, and provides new guidance.

Mineral soils

Tier 1

Default reference C stocks are found in Table 2.3 of Chapter 2, and stock change factors for previous land uses can be found in the relevant Chapters (for Forest Land in Section 4.2.3.2, Cropland in 5.2.3.2, Grassland in 6.2.3.2, and Other Land in 9.3.3.2). Default stock change factors for land use after conversion (Settlements) are not needed for the Tier 1 method for Settlements Remaining Settlements because the default assumption is that inputs equal outputs and therefore no net change in soil carbon stocks occur once the settlement is established. Conversions, however, may entail net changes and it is good practice to use the following assumptions:

(i) for the proportion of the settlement area that is paved over, assume product of F_{LU}, F_{MG} and F_I is 0.8 times the corresponding product for the previous land use (i.e., 20% of the soil carbon relative to the previous land use will be lost as a result of disturbance, removal or relocation);

(ii) for the proportion of the settlement area that is turfgrass, use the appropriate values for improved grassland from Table 6.2, Chapter 6;

(iii) for the proportion of the settlement area that is cultivated soil (e.g., used for horticulture) use the no-till F_{MG} values from Table 5.5 (Chapter 5) with F_I equal to 1; and

(iv) for the proportion of the settlement area that is wooded assume all stock change factors equal 1.

Tier 2

Refining Application of Default Equations

Estimation of country-specific stock change factors is probably the most important development associated with the Tier 2 approach. Differences in soil organic C stocks among land uses are computed relative to a reference condition, using land-use factors (F_{LU}). Input factor (F_I) and management factor (F_{MG}) are then used to further refine the C stocks of the settlement management classes. Additional guidance on how to derive these stock change factors is given in *Settlements Remaining Settlements*, Section 8.2.3.2. See the appropriate section for specific information regarding the derivation of stock change factors for other land-use sectors (Forest Land in Chapter 4, Cropland in Chapter 5, Grassland in Chapter 6, Wetlands in Chapter 7, and Other Land in Chapter 9). Reference C stocks can also be derived from country-specific data in a Tier 2 approach and should of course be consistent across the land uses (i.e., Forest Land, Cropland, Grassland, Settlements, Other Land), and therefore coordinated among the various teams conducting soil C inventories for AFOLU.

The depth for evaluating soil C stock changes can also be extended, beyond the 30 cm depth, with the Tier 2 method. This will require extending the depth of the reference C stocks (SOCref) and stock change factors for all land uses (i.e., FLU, FI, and FMG) to ensure consistency. Variable depths between reference stocks and stock change factors are likely to introduce biases into the inventory estimates that are computed using Equation 2.25.

Furthermore, it may be an improvement to estimate carbon stocks on a mass equivalency basis if developing country-specific factors for F_{LU}. This is because the soil weight in a certain soil depth changes with the various activities associated with land use change, for example uprooting, land leveling, and rain compaction due to the disappearance of the cover of tree canopy. In addition, cropland soils usually tend to have relatively higher densities than the soils in forest land and possibly grasslands or wetlands. Settlement management may also impact the soil bulk density. In such case, the comparison of the soil C stocks between the cropland, settlement, grassland, wetland, or forest land within the same depth is not appropriate. It is more robust to compare the carbon stock on an equivalent mass basis, with the stock change calculated on the same weight soil. This method is also recommended when the bulk density between cropland, grassland, wetland, settlement and forest land is remarkably different even if the site is within close proximity. However, it is important to realize that all measurements and associated stock change factors across all land uses must be on an equivalent mass basis if this method is applied. This will be challenging and possibly not even practical when compiling a national inventory.

Three-Pool Steady-State C Model

Default parameters are provided for the three-pool steady-state C pool equations (Chapter 2, Section 2.3.3.1, Table 2), but parameters may be revised if experimental data are available to test the model.

Tier 3

Constant emission rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Chapter 2, Section 2.3.3.1 for further discussion.

Organic soils

No Refinement, See 2013 Wetlands Supplement

8.3.3.3 CHOICE OF ACTIVITY DATA

This section has further elaboration on methods, and provides new guidance.

Mineral soils

Tier 1

The amount of land converted to Settlements, stratified by climate region and soil type, is needed to estimate the appropriate stocks at the Tier 1 level. This can be based on overlays with suitable climate and soil maps and spatially-explicit data of the location of land conversions. Detailed descriptions of the default climate and soil classification schemes are provided in Chapter 3. In the absence of specific information, default area within the settlements that is paved over should be estimated as the non-greenspace proportion of the total area, using the data in Table 8.3, and the same Table can be used to partition the greenspace area into wooded areas and non-wooded areas. The latter may be assumed all to be turfgrass unless data are available on the area otherwise cultivated.

Tier 2

Refining Application of Default Equations

See guidance for Tier 1 Method.

Three-Pool Steady-State C Model

This method requires soil C input data based on the amount of biomass that is converted to dead organic matter annually. This rate will vary depending on plant production, management activity, natural disturbances, and other environmental variables. Removals or reductions in dead organic matter are subtracted from the soil C input amount, which could occur with practices such as salvage logging operations, collection of coarse woody debris or crop residues, burning of grasslands, livestock grazing, and other practices. Disturbance events, such as pest outbreaks, may increase the dead organic matter, and therefore the C input to soils. It is good practice to use country-specific methods for estimating C input to soils, but defaults approaches are provided for cropland (Section 5.2.3.3) and grassland (Section 6.2.3.3).

Beyond the amount of C input, the average lignin and nitrogen contents of the new dead organic matter are also required to estimate the amount of C in the three soil pools. Tillage management data are also required for croplands (proportion of full tillage, reduced tillage and no-till), and irrigation data for any lands that are provided supplement water.

Additional ancillary data for this method include monthly weather data and soil texture (i.e., sand content), which are available from global weather and soils datasets if country-specific data are not available, such as the CRU climate dataset (https://crudata.uea.ac.uk/cru/data/hrg/), and the Harmonized World Soil Database (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/), respectively.

Tier 3

For application of dynamic models and/or a direct measurement-based inventory in Tier 3, similar or more detailed data on the combinations of climate, soil, topographic and management data are needed, but the exact requirements will depend on the model or measurement design.

Organic soils

No Refinement. See 2013 Wetlands Supplement

8.3.3.4 UNCERTAINTY ASSESSMENT

No Refinement

8.4 COMPLETENESS, TIME SERIES CONSISTENCY, QA/QC AND REPORTING

No Refinement

8.5 BASIS FOR FUTURE METHODOLOGICAL DEVELOPMENT

The section is updated by deletion of the sentences no more relevant. [This section updated by completion of updating Table 8.1 and 8.2]

Gaps in this methodology exist because sufficient data are not available to quantify all of the pools and fluxes of greenhouse gases in settlements. Obvious gaps include:

Methodology for estimating emissions of non-CO_2 greenhouse gases (N_2O and CH_4);

Detailed methodology to account for carbon stocks other than live biomass and soils (specifically, dead wood and litter);

Discussion of carbon stocks and fluxes from turfgrass and turf management;

~~Discussion of carbon stocks and fluxes from gardens and other herbaceous plants; and~~

~~A generalized methodology to account for different classes of settled lands, with different amounts of woody and non-woody vegetation and different types of management.~~

Non-CO_2 greenhouse gases. While some evidence exists to support the idea that nitrous oxide fluxes may be enhanced in urban areas relative to the native condition (Kaye *et al*., 2004), this result likely depends on the native condition (i.e., the climate and region in which the settlement is located) and the management regime typically applied in that settled area. Additional data are required before conclusions about the impact of settlement on non-CO_2 greenhouse gas fluxes can be drawn.

Dead wood and litter. Dead wood is a class variously composed of fallen or pruned branches or trees, or dead standing trees not yet replaced with live individuals. This dead wood may be burned or disposed of as solid waste, used for composting, left to decay either in-site or off-site. This material is treated in this methodology as a loss from the live biomass term. Because dead wood is likely to be carried off-site in settlements (rather than left on-site to decay as in forests), a more detailed methodology developed in the future might account for the proportion of dead wood taken to landfills, disposed of in compost piles, burned, or left on-site to decay. The portion taken to landfills or composted might be treated as harvested wood products (HWP) or as waste, both of which are treated in other sections of the *Guidelines*.

Turfgrass and turf management. Turfgrass biomass consists of roots, stubble, thatch, and above-ground components. Though estimates of turfgrass productivity have been published (Falk, 1976; Falk, 1980; Qian *et al*., 2003), grass decomposes quickly and there is little information about the overall accumulation of biomass in the longer-lived components of turf biomass. Turfgrass allocation to the above-ground and below-ground components also depends on the management and mowing regime. Because of the lack of generalizable information on this topic, as well as the lack of activity data quantifying the area covered by turfgrass in settlements, there is currently no detailed methodology describing carbon removed by turf systems. A more detailed methodology would require additional information on turf productivity, turfgrass turnover, and allocation to different plant components as it varies with management regime. Of course, the activity data required to implement this methodology would include information on management regimes and the proportion of settlements covered by turfgrass.

~~**Gardens and other herbaceous plants**. Similar to the situation with turfgrass, information does not exist describing the annual biomass accumulation and allocation of garden plants to different above-ground and below-ground parts. Similarly, information is not available describing the variation in plant productivity with management regime. Activity data required to implement a more detailed methodology would include information on management regimes and the proportion of settlement area covered by this type of vegetation. These are mainly garden plants, so sampling them in private gardens presents the additional problem of their likely disturbance and consequent denial of access to them (cf. Jo and McPherson, 1995).~~

Land classes. A more detailed methodology would benefit from a consistent set of definitions of land classes *within* settlements that could be applied to any country regardless of its climate, native vegetation, or typical settlement regime. This would make settlements parallel to other land uses – Forest Land, Grassland, Cropland, Wetlands – which are easily defined based on a set of measurable and objective parameters. Some research has been applied in this direction (Theobald, 2004), but current classifications are inconsistent. While the rate of carbon sequestration per unit of tree crown cover is fairly consistent, for example, the overall rate of carbon storage per unit of settlement area depends entirely on the relative amounts of tree and turfgrass cover within that settlement. This land classification would be part of the set of activity data collected by countries, and the detailed methodology could be developed and applied consistently based on those land cover data. This type of land-use classification would also enable countries to account for changes in carbon storage resulting from management changes within areas broadly classified as settlements. For example, when vacant plots are developed, the adventitious vegetation remaining in the non-built areas might be replaced with landscape species differing in ability to store carbon.

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