USCP Appendix J: Forest Land and Trees

Primary authors:
Richard Birdsey, Woods Hole Research Center
Nancy Harris, World Resources Institute
Donna Lee, Climate and Land Use Alliance
Stephen Ogle, Colorado State University

Reviewers:
Maia Davis, Metropolitan Washington Council of Governments
Kendall DeLyser, American Forests
Alexa Dugan, US Forest Service
Joe Fargione, The Nature Conservancy
Wee Kean Fong, World Resources Institute
Sandra Hamlat, East Bay Regional Parks District
Emily McGlynn, University of California, Davis
Laura Miller, Department of Environmental Protection, Montgomery County
Sarah Mincey, Indiana University
Tim Pearson, Winrock International
Neelam Singh, World Resources Institute
Eric Sprague, American Forests

Contents

Note: This report refers to a Guidance Document that will provide more detailed information for applying this appendix. The Guidance Document will be available by the end of 2019.

Abbreviations

AFOLU	Agriculture, Forests, and Other Land Use
C	carbon
CDL	Cropland Data Layer
CH_4	methane
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DBH	diameter at breast height
FIA	Forest Inventory and Analysis
GHG	greenhouse gas
GPC	Global Protocol for Community-Scale Greenhouse Gas Inventories
HWP	harvested wood products
IPCC	Intergovernmental Panel on Climate Change
N	nitrogen
N_2O	nitrous oxide
NLCD	National Land Cover Database
NO_x	nitrogen oxides
tC	metric tons carbon
tCO_2e	metric tons carbon dioxide equivalent
UNFCCC	United Nations Framework Convention on Climate Change
USCP	ICLEI's U.S. Community Protocol

L.0 Introduction

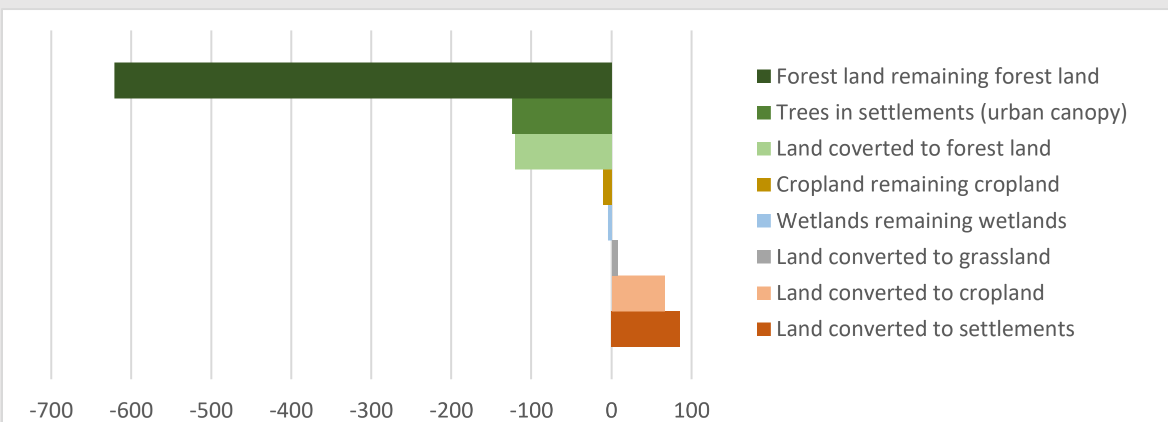
L.0.1 Land-based greenhouse gases and current coverage in this appendix

How lands are managed—from forest conservation to agricultural practices—can affect the exchange of greenhouse gases (GHGs) between the atmosphere and land. GHGs from land use differ from those of energy, industrial processes, and waste in several ways.[1] For example, land use can result in GHG emissions, but it also can lead to removals of carbon dioxide (CO_2) from the atmosphere. In the United States, land use is a net sink, with removals of CO_2, mostly into forests and trees, exceeding emissions of CO_2 (Box 1). The net effect of land use is estimated based on the change in carbon stocks, or stores of carbon in biomass, litter, dead wood, and soils. Different land uses have different levels of carbon stocks. Therefore, changes in land use can result in changes in carbon stocks, affecting GHG emissions and removals. Different management practices on lands can affect result in emissions or removals.

Box 1. Contribution of land to the United States' greenhouse gas inventory

The most recent US GHG inventory (US EPA 2019) highlights that forests and urban trees are a large carbon sink (they remove CO_2 from the atmosphere). Key sources of emissions include land (mostly Forest Land, followed by Grassland and Cropland) converted to Settlement and land (mostly Forest Land, followed by Grassland) converted to Cropland.

Box figure. Key land-related emissions and removals in the US GHG inventory in million tCO_2
Note: A positive number denotes emissions, negative numbers are removals (i.e. CO_2 sequestration)



Source: US EPA 2019

Land management is critically important to mitigating climate change. However, by most accounts, a GHG inventory for land use is different and more complicated than for other sectors. In addition to both emitting and removing GHGs, there are multiple carbon pools that respond differently to management activities and natural disturbances, interannual variability is high, and measurements may not be as precise as it is in other sectors. For these reasons, this appendix devotes considerable text up front to assist inventory compilers in partitioning land into logical classes and stratifying and substratifying land to improve estimates. It describes how satellite observations and field measurements are combined to generate estimates of emissions and removals. Where possible, it simplifies methods and explains terminology and definitions that may not be widely known while preserving the ability to provide useful

[1] For more information on the differences between GHGs from land use versus other sectors, see Iversen, Lee, and Rocha (2014).

GHG inventory information for informing policies and practices regarding climate change mitigation at community scale. Table 1 summaries the methodologies and related data requirements for estimating GHGs from land included in this appendix.

Table 1. Summary of methodologies included in this appendix

Methodology	*Data required*	*Section*
Defining the inventory analysis period	• Information about time periods over which data on land cover and carbon stocks are available	L.1
Representation of land	• Maps of community land cover for at least two points in time, including information on how each land cover category in the map was defined	L.2
Estimating GHGs from Forest Land	• Spatial (GIS) data related to land management, if relevant (e.g., "working" or managed forests, protected areas, etc.) • Carbon stock (and change) of Forest Land from national forest inventory databases • Mill records on quantity and type of harvested wood products, if relevant	L.4
Estimating GHGs from trees outside Forest Land	• Tree inventory data and/or maps of canopy cover collected over inventory analysis period • Carbon stock (and change) for trees outside forests from national forest inventory databases	L.5

The Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories suggests that land-based GHGs be reported in six main categories: Forest Land, Cropland, Grassland, Settlement, Wetlands, and Other Lands. Both emissions and removals (i.e., carbon sequestration) can occur in each of these categories. GHG inventories typically report the net GHGs for each category.

This appendix is organized as follows. Sections L.1 to L.3 provide a broad framing to report on all land uses. Sections L.4 and L.5 provide guidance for estimating GHG emissions and/or removals from Forest Land and "trees outside forest," including conversions between Forest Lands and other land uses.

For Forest Land (Section L.4), all transition categories are covered—Forest Land Converted to Non-Forest[2], Non-Forest Converted to Forest Land, and Forest Land Remaining Forest Land. Trees may be present in other types of non-forested land in the community (Cropland, Settlement, Grassland, Wetland, Other Land). Section L.5 provides guidance on estimating GHGs from the tree component of these lands as a preliminary step toward covering non-Forest Land categories more comprehensively in the future. Urban trees are included in the Settlement category.

Updates to this appendix may provide more detailed guidance for other land uses (e.g., Cropland, Grassland, Wetland).

This appendix is based largely on IPCC guidance (written for national-scale inventories) and protocols used for the US GHG inventory. It recommends the following in applying the IPCC guidance to US community-scale GHG inventories:

[2] In the US GHG inventory and IPCC guidelines, Forest Land converted to Other Land categories is reported in the end-use category (e.g., Forest Land to Cropland is reported in the Cropland category); including forests conversions in the Forest Land category is an interim simplification until this Appendix is updated with guidance for other land uses.

- Estimating baseline GHGs for land use using an annual average over a period of approximately 5–10 years and updating the GHG inventory over time based on data availability (Section L.1).
- Classifying all lands into the six IPCC land use categories (Section L.2), even if not all land use–related emissions or removals are estimated by the community.
- Further stratifying data into subcategories, where doing so can improve the GHG estimates or provide information useful to community-scale policy (L.4, Step 1).
- Using simplified methods to estimate carbon stock changes rather than omitting a category, as long as information quality is sufficient to inform policies (e.g., use the "committed" approach rather than track lands over time [Section L.2.2 and Section 4]).
- Using readily available databases (such as the National Land Cover Database and Forest Inventory and Analysis data) that conform to national standards and represent most areas of the conterminous United States while also providing options for communities to substitute local data if available and useful for specific land conditions or policies of local interest.

The recommendations in this appendix should be applicable to most communities. They often include simplifications appropriate for community-scale GHG inventories. Other options for estimating GHGs from land are possible; communities may wish to tailor methods to meet their needs. The annex to this appendix contains a more general set of equations that could be used in such cases.

Box 2. Reasons to protect forests and trees beyond carbon

This appendix focuses on measuring carbon stock changes and non-CO_2 GHGs from Forest Land and trees outside forests. But there are reasons why communities may want to take actions related to Forest Land and trees that go beyond the carbon storage and sequestration they provide. They include (but are not limited to) the following:

- **Reducing the heat island effect**: Increasing the urban canopy can reduce the urban heat island effect, by increasing shade and evapotranspiration. Trees can decrease demand for energy and the costs of air conditioning (and reduce heat-related illness), resulting in lower air pollution and GHG emissions.
- **Managing watersheds**: Forests and trees help protect important watersheds. They also intercept and store rainwater, reduce runoff volume, and delay peak flows. Trees also help remove pollution and sediment from stormwater.
- **Improving human health**: An extensive and healthy urban forest can significantly improve air quality by reducing the formation of ozone (smog). Trees can also remove particulate matter and other pollutants, such as carbon monoxide, sulfur dioxide, and nitrogen dioxide, from the air. Studies also show a wealth of social, physical, and psychological benefits that come from urban forests.[3]

Actions by communities can also have indirect impacts on Forest Land and trees. This appendix does not quantity their effect on terrestrial carbon. These effects include (but are not limited to) the following:

- **Consumption-based or demand-side emissions:** Emissions and removals from lands can result from the consumption of and demand for commodities. For example, a recent study estimates that four commodities—beef, palm oil, soy, and timber/pulp/paper—accounted for at least 40 percent of deforestation, mostly in the tropics (Henders, Persson, and Kastner 2015). The embodied emissions from

[3] For more information on the benefits of urban trees, see Talking Trees: An Urban Forestry Toolkit for Local Governments, published by ICLEI (Bell and Wheeler 2006).

consumption of such products—or from use of bioenergy—depend to a great extent on where, and how much of, these commodities are produced.

- **Substitution effects of harvested wood products**: Section L.4 covers methods to estimate the GHG emissions and removals from harvested wood products as part of the GHG inventory. It does not include the substitution effects when wood is used in place of, for example, fossil fuels for energy use or cement and steel for buildings. Demand for, and use of, long-lived wood products in particular can have a positive climate benefit by reducing emissions associated with producing structural materials and providing economic incentives for reforestation that otherwise would not occur. Communities may wish to consider substitution effects when evaluating mitigation options, but these effects are not typically included in GHG inventories (unless the substitution occurs within the boundaries of the community itself [e.g., reduces fossil fuel use]).

L.0.2 Land-based greenhouse gas emissions and interactions with other sectors

The use of land, particularly forests, interacts with other sectors in a GHG inventory, particularly energy (e.g., through the burning of biomass or agricultural residue for energy) and waste (e.g., through biomass that goes to landfill). Biomass from forests is also used in harvested wood products, which store carbon for various periods of time, from short periods (e.g., paper packaging) to very long periods (e.g., furniture or building construction). The substitution and market effects of using such products can also have impacts on other sectors—for example, using wood rather than energy-intensive materials such as cement or steel for buildings.

Full and accurate estimation of land use impacts on GHGs requires inclusion of all these linked systems. However, such systems often cross jurisdictional boundaries. For example, wood produced within a community may be used for energy or wood products outside the community. Biomass waste may end up in a landfill within (or outside) the community.

When covering land-related emissions and removals, some GHG inventory guidance frameworks apply the concept of “scopes” to help organize the inventory process (Table 2). This appendix primarily involves Scope 1 (i.e., GHGs from lands within the community boundary and harvested wood products using the production approach [see Section L.4, Step 6]).

Table 2. Scopes 1, 2, and 3 in relation to greenhouse gas inventories

Scope	*Greenhouse gases covered*
1	GHGs from sources and sinks located within the community boundary
2	GHGs occurring as a consequence of the use of grid-supplied energy within the city boundary
3	All other GHG emissions or removals that occur outside the community boundary as a result of activities taking place within the community boundary

Table 3 provides a crosswalk between how GHGs from Forest Land and trees outside forests are treated in this appendix and the Global Protocol for Community-Scale Greenhouse Gas Inventories (GPC), the Intergovernmental Panel on Climate Change 2006 Guidelines for National Greenhouse Gas Reporting (IPCC), and their representation in the US GHG inventory.

Table 3. Crosswalk among ICLEI's USCP, GPC, IPCC Guidelines and the US GHG Inventory

Land-related GHGs	*ICLEI's U.S. Community Protocol (USCP)*	*Global Protocol for Community-scale GHG Inventories (GPC)*[a]	*IPCC Guidelines for National GHG Inventories*	*US Greenhouse Gas Inventory*
Forest	Comprehensive reporting (through this appendix)	BASIC+[b] only, emissions only	Comprehensive reporting	Comprehensive reporting[c]
Trees outside forests			Reporting in land category (outside forest)	Carbon stock changes in urban trees[e]
Biomass / residue burning for energy[f]	Biomass loss included in this appendix on land use; non-CO_2 emissions reported in stationary energy in the built environment (Appendix B)	Biomass loss reported in Agriculture, Forests, and Other Land Use (AFOLU); non-CO_2 emissions reported in Scope 1 stationary energy	Biomass loss reported under Forest category[g]; non-CO_2 emissions reported in energy sector	Biomass loss reported in Forest Land Remaining Forest Land[h]; non-CO_2 emissions reported in energy sector
Biomass burning on site; no energy recovery	Reported through this appendix	Reported in AFOLU	Reported in AFOLU, Forest Land	Reported in Land Use, Land-use Change and Forestry (LULUCF) chapter, Forest Land
Harvested wood products (HWP)	Embedded within Consumption (Appendix I)	Reported in AFOLU, emissions from other sources (Chapter 10.5.8)	Reported in AFOLU, Forest Land/HWP (choice of approaches)	Reported in Forest Land/HWP, using production approach
Biomass in landfill	Reported in solid waste (Appendix F), using either first-order decay or methane commitment, depending on relevant activity data	Reported in waste sector (Chapter 8); garden, park, and wood waste included as type of municipal solid waste; IPCC Waste model recommended	Non-CO_2 emissions reported in waste sector; CO_2 reported in AFOLU, biomass carbon stock changes, and HWP	Non-CO_2 emissions reported in waste sector; carbon stock changes in yard trimmings in landfills are included in land use reporting under Settlements

[a] As of the time of publication, the GPC is being updated; it is suggested to refer to the GPC for updates.
[b] The GPC offers two options for reporting, BASIC and BASIC+. The BASIC level covers scope 1 and 2 emissions from stationary energy and transportation, as well as scope 1 and 3 emissions from waste. BASIC+ includes additional GHGs, including emissions from agriculture, forests and other land use (AFOLU), industrial processes and product use (IPPU) and Scope 3 emissions from transportation and electricity, heat, steam and cooling transmissions and distribution losses.
[c] With exception to U.S. Territories, Hawaii and portions of managed forests in Alaska (as of the publication of this Appendix; this is an area for improvement in the U.S. GHG inventory)
[e] Currently trees in other lands, such as agroforestry practices, alley cropping, windbreaks, silvopasture systems (that occur in Cropland)—are not estimated in the US GHG inventory (this is an area for improvement in the US GHG inventory).
[f] In the case of biomass burning for energy, CO_2 emissions from biomass losses (at the forest "stand") often occur in a different community than emissions from burning biomass (at the "stack"). Because of the way such emissions are reported, the community in which the harvesting takes place would report an emission caused by loss of biomass (which may be recovered in the longer term if the biomass returns); the community that is burning bioenergy would report only the non-CO_2 emissions from burning the biomass (not the CO_2 emissions).
[g] The IPCC guidelines recommend reporting CO_2 loss from biogenic emissions as carbon stock change in AFOLU and as an "information item" in the Energy sector reporting.
[h] The US GHG inventory uses a "stock-change" method to estimate GHGs from forests that inherent includes all carbon stock changes.

L.0.3 Units of measurement and related terminology

The most relevant GHG for Forest Land is CO_2, which is related to carbon stock changes.

All carbon stock computations are performed in terms of mass of carbon (C) per unit area. In metric units, this translates to metric tons (t) per hectare (tC per hectare or tC ha^{-1}). Metric units are recommended, as they are the internationally accepted units of measure for GHG inventories. An example stock estimate is 100 metric tons C ha^{-1}.

Rate data are reported in terms of change in C/ha over time, as in tC per hectare per year (tC $ha^{-1} yr^{-1}$). An example stock change estimate is 1.0 metric tons C ha^{-1} yr^{-1}.

All C biomass is referenced to its dry weight basis and the fraction of C in biomass. For the purpose of this Protocol Appendix, the recommended value for fraction of dry biomass that is C is 0.47[4].

It is important to differentiate between units of carbon and carbon dioxide equivalents (CO_2e) and report the appropriate units to the reporting entity. It is recommended to use metric units and to report GHGs in metric tons of CO_2e. This convention puts all carbon mass estimates in units of the emission gas, CO_2, which can be derived by multiplying the carbon mass by 44/12.

Table 4 describes the terminology used to describe GHG fluxes in the land sector.

Table 4. Common terminology used to describe GHG fluxes in the land sector

Context	*Transfer of GHG to atmosphere from land*	*Transfer of GHG from atmosphere to land*
Describing flow of GHG	Emission	Removal
Describing flow of GHG	Source	Sink
Calculating change in stock	Loss	Gain
Reporting convention	Positive number (+)	Negative number (-)

L.0.4 Estimating uncertainty

Estimating overall uncertainty can be more complex for forest and tree-related GHGs than for GHGs in other sectors because there are more sources of potential error. Maps used to support the interpretation of land cover and change can contain classification errors. Uncertainties may also be significant in the underlying data used to determine emission and/or removal factors, particularly if these factors are derived from very few measured plots over relatively small and/or heterogeneous land areas. In addition to the uncertainty associated with sampling and measurement, there may be significant bias in the estimates. For example, if an emission factor associated with harvesting disturbance is based on a regional average, the true value for a community area within the region may be higher or lower than the regional average value used.

When calculating uncertainty for a value with multiple sources of potential error, it is necessary to combine (or "propagate") the uncertainties using statistical formulae. The IPCC guidelines (IPCC 2006) provide a simplified method. A more formal Monte Carlo simulation makes use of the probability distributions of key input variables to calculate the estimates many times until an uncertainty estimate

[4] Value from IPCC 2006 Guidelines, Forest Land chapter, Table 4.3, page 4.48.

can be made. For some input variables, probability distributions may not be available; uncertainty is then estimated based on expert opinion.

This version of the Protocol does not provide a specific approach to estimating uncertainty. It is recommended that communities consider the sources of uncertainty and apply common sense procedures to select data that best represent the activities and land base of their community. For example, in the absence of local data, communities can reduce error by choosing or developing emission and removal factors that represent conditions similar to those in the community. When communities use off-the-shelf national databases, such as the National Land Cover Database, a customized accuracy assessment (such as Olofsson et al. 2014) can be implemented to improve the area estimates (activity data) and calculate a confidence interval around the land cover change assessment. If the US Forest Service Forest Inventory and Analysis (FIA) is used, the uncertainty of sampling may be derived directly from the FIA database. Other sources of uncertainty, such as the uncertainty of the statistical models used to estimate variables such as carbon in biomass or soils, are not be as easily estimated.

As a rough guideline about uncertainty of estimates involving the forest sector, the US national GHG inventory reports uncertainty (based on Monte Carlo simulations) in the range of ±45 percent (with 95 percent confidence) for Forest Land Remaining Forest Land (US EPA 2019). Estimates of GHGs for Forests and trees outside forests for smaller domains, such as communities, can have similar or higher uncertainties, particularly for strata that may not have enough data to capture the characteristics of very small areas. However, performing a GHG inventory of forests and trees can provide a community with sufficient information about the relative magnitude of the sector's contribution to atmospheric GHGs as well as its impact on climate change mitigation (i.e., the change or directionality in GHG estimates over time).

L.1 Defining the Inventory Analysis Period

Estimating GHG emissions and removals from land use requires knowledge of both land use and change. Information is required from at least two points in time to compare whether and how land use has changed over a given period. Data from one point in time can provide information only on carbon stocks; a GHG inventory requires information on GHG fluxes (changes in carbon stocks over time).

The inventory analysis period is typically defined by:

- the year(s) of interest to estimate GHGs from land use and change;
- the years for which data are available.

A community may wish to develop information for a reference level against which the community can set climate goals.[5] A reference level for land use should be expressed in the same units as the reference level (often a base year) used for other sectors (i.e., tons of CO_2e). However, annual data are often unavailable for land use change, which are needed to estimate GHGs. In addition, several years of data (5–10 years) may be more optimal for setting a reference level, because of the typically high interannual variability of land-based CO_2 fluxes driven by anomalies such as natural disturbances and weather from one year to the next. Therefore, to estimate reference GHGs from land, it is recommended that a reference period (the range of years from which an annual average is estimated) be chosen that straddles the base year used for other sectors (see the example in Box 3).

After GHGs from land use are estimated for the reference period, subsequent GHG estimates are made using various analysis periods, based on the years for which a GHG inventory is compiled for other sectors and the availability of land use data. Such periods need not be the same length as the reference period; data are averaged over each period and annualized.

To assess trends in GHGs, it is important to use the same land use definitions (classifications), methods, and data sources in each inventory. If changes are made—which is often the case, as advances in land cover monitoring are deployed—the time series should be recalculated (including the reference period and all subsequent periods) using the new methods, to promote consistency of the estimates across time.

Box 3. Using the National Land Cover Database

The US Geological Survey (USGS) updates the National Land Cover Database (NLCD) every five years; it is available for 2001, 2006, 2011, and 2016.[6] If a community decides to use the NLCD as the basis of land use change estimates and choses a base year of 2005 to set goals for other sectors (e.g. 80% reduction from 2005 emissions by 2050), the community may estimate average annual GHGs over a reference period of 2001–11 or 2001–06 and use these estimates as the baseline for land-based GHGs. This reference period would be comparable to the 2005 base year for other sectors.

Choosing a longer period helps avoid capturing an anomalous year and can smooth out the interannual variability that can be caused by, for example, weather patterns (such as El Niño effects). Choosing a

---

[5] The Global Covenant of Mayors Common Reporting Framework states that a reference level "should be the same as the base year used in the NDC or as set by Regional/National covenants. Where the base year is different from the NDC (e.g., where a city has previously adopted another base year or due to a lack of data availability), this shall be explained."

[6] The US Geological Survey may add additional time periods in the future.

shorter period provides data that are more closely aligned with the base year used for other sectors and used to set targets.

In the future, a community may compare annualized data from other inventory analysis periods, such as 2011–16 and 2016 to the next NLCD year. These periods need not be longer, as more time steps can help develop a more comprehensive time series and inform a deeper understanding of trends in land-based GHGs.

A community may decide to use an alternative dataset to the NLCD. Table 6 (Section L.2.3) provides several off the shelf options. Alternatively, a community may collect its own forest/tree cover data at periodic intervals. In this case, the reference period and subsequent analysis periods would be based on the dates over which data were collected. If a community uses its own data, it is important that there be consistency, over time, in the methods used to generate the data.

L.2 Representation of Land

L.2.1 Delineating the land base

Before estimating land-related GHG emissions and removals, a community must first determine the land area over which to estimate them. Typically, it is the land directly affected by anthropogenic management ("managed land" [see Box 4]). It is recommended that communities consider all land within the administrative boundaries of their jurisdictions as managed.

Exceptions for deviating from the recommended approach may exist, however, for example:

- Areas owned/managed by the community that are outside the jurisdictional boundary may be added to the land base;
- Areas outside the jurisdictional boundary that are not directly owned by the community but that are influenced by within-boundary planning and development decisions may also be included in the land base;

Land within the jurisdictional boundary over which the community has little or no authority (e.g., federal or state land) or land designated by the community as unmanaged (Box 4) may be excluded from the land base. However, to improve understanding of how the community jurisdiction fits into the larger context of land management decisions that affect whole landscape, all lands within a community's jurisdictional boundaries should be included in the inventory. Lands over which there may be different authorities could then be separated by designating substrata (see Section L.4, Step 1).

Box 4. Managed versus unmanaged land

IPCC guidelines separate land into two categories: managed and unmanaged. The IPCC defines *managed land* as land on which human interventions and practices have been applied to perform production, ecological, or social functions. The concept of managed lands was developed to separate the effects of anthropogenic (human-caused) activities from non-anthropogenic (natural) effects on GHGs. For reporting GHGs, all land in the United States except some land in Alaska is classified as managed by the federal government. Large areas in Alaska that are largely inaccessible or far from settlements and roads are considered unmanaged, because of the lack of direct human intervention.

In practice, separating out natural from human-caused emissions or removals can be a challenge. For example, fires—which can lead to significant emissions—are often difficult to attribute entirely to either cause. IPCC guidance is to report GHG emissions and removals on managed lands as a proxy for anthropogenic emissions and removals.

It is recommended that communities consider all land as managed to remain consistent with federal (and potentially state) GHG reporting. If a portion of community land is designated as unmanaged and excluded from the inventory, justification should be provided on the methods used to delineate them and geospatial boundaries provided in documentation, as applicable.

L.2.2 Land use classification

It is recommended to define and classify all community lands into six land use classes: Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land.[7] This classification forms the basis for estimating and reporting GHG emissions and removals from all land use and land use conversions. If needed for calculating GHGs, informing local decision making, or reporting purposes, additional subcategories may be included.

Care should be taken to avoid overlaps or omissions in the classification of the land base. For example, overlaps can occur if trees on farms are included as both Forest Land and Cropland; this land should be represented as only one land use class. The classification should represent land use categories consistently over time, so that changes in data or methods and/or artificial discontinuities in the time-series data are not represented as land use changes. As the inventory analysis period is likely to span several years, seasonal changes in land use that may occur within a single year are not considered.

Box 5 provides the definitions for each land use class applied by the US federal government in compiling the national GHG inventory. It is recommended that communities align with the definitions applied by the federal (or state) government if possible, to ensure consistency with national (or state) reporting. A community may, however, decide to use a land use classification system that diverges from that used by the federal (or state) government for policy or other reasons. For example, a different classification system may be critical to improve the estimation of GHG emissions. Alternatively, a particular classification may be selected that is consistent with laws and policies relevant to land management that the community wishes to monitor as part of its climate action.

Box 5. Land use definitions in the US Greenhouse Gas Inventory

The US National GHG inventory defines the six IPCC land use classes as follows:[8]

- **Forest Land**: Areas at least 120 feet wide (36.6 meters) and 1 acre (0.4 hectare) in size with at least 10 percent canopy cover (or equivalent stocking) by live trees. Land with such tree area and cover is not classified as forest if completely surrounded by urban or developed lands (such land is classified as Settlements); land that is predominantly under agricultural land use is also not considered Forest.
- **Cropland**: Areas used for the production of adapted crops for harvest. This category includes both cultivated (row crops, close-grown crops) and non-cultivated (hay, orchards) land.
- **Grassland**: Areas on which the plant cover is composed principally of grasses; grass-like plants (i.e., sedges and rushes); forbs; or shrubs suitable for grazing and browsing. It includes both pastures and native rangelands.
- **Wetland**: Land covered or saturated by water for all or part of the year, as well as areas of lakes, reservoirs, and rivers.

[7] The six land use classes are consistent with those defined by the IPCC Guidelines for National GHG inventories and used by the US Environmental Protection Agency (EPA) in developing the US GHG inventory.

[8] For more information on each land use class, see the US GHG Inventory, Chapter 6: Land Use Land use Change and Forestry, at https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks. The National Resources Inventory is the official source of data for land use and land use change on non-federal lands for most of the United States, except Forest Land, which is based on Forest Inventory and Analysis (FIA) data. Land use and land use change data for federal lands and Alaska are based on a combination of FIA data for Forest Land and the National Land Cover Database for other land uses.

- **Settlement**: Developed areas consisting of units of 0.25 acres (0.1 hectare) or more that include residential, industrial, commercial, and institutional land (including farm buildings and road networks). Also includes tracts of less than 10 acres (4.05 hectares) that may meet the definitions for Forest Land, Cropland, Grassland, or Other Land but are completely surrounded by urban or built-up land.
- **Other Land**: Bare soil, rock, ice, and all land areas that do not fall into any of the other five land use categories; carbon stock changes and non-CO_2 emissions are not estimated for Other Land, because these areas are largely devoid of biomass, litter, and soil carbon pools.[9]

Both the US National GHG inventory and the GPC provide a hierarchy for areas that fall into more than one category of the classification. In such cases, lands are assigned the following classes by priority: Settlements > Cropland > Forest Land > Grassland > Wetlands > Other Land. The US national inventory report provides the following underlying rationale for this ranking:

> *Settlements are given the highest assignment priority because they are extremely heterogeneous with a mosaic of patches that include buildings, infrastructure, and travel corridors, but also open grass areas, forest patches, riparian areas, and gardens. The latter examples could be classified as Grassland, Forest Land, Wetlands, and Cropland, respectively, but when located in close proximity to settlement areas, they tend to be managed in a unique manner compared to non-settlement areas. Consequently, these areas are assigned to the Settlements land-use category. Cropland is given the second assignment priority, because cropping practices tend to dominate management activities on areas used to produce food, forage, or fiber. The consequence of this ranking is that crops in rotation with pasture are classified as Cropland, and land with woody plant cover that is used to produce crops (e.g., orchards) is classified as Cropland, even though these areas may meet the definitions of Grassland or Forest Land, respectively. Similarly, Wetlands are considered Croplands if they are used for crop production, such as rice or cranberries. Forest Land occurs next in the priority assignment because traditional forestry practices tend to be the focus of the management activity in areas with woody plant cover that are not croplands (e.g., orchards) or settlements (e.g., housing subdivisions with significant tree cover). Grassland occurs next in the ranking, while Wetlands and then Other Land complete the list.*

Once definitions are applied, they should be used consistently in future GHG inventories so that inventories are comparable. [10] If a definition is changed, the historical time series of GHG estimates should be recalculated to reflect the change in definition.

---

[9] The exception is when Forest Land, Cropland, Grassland, Wetland, or Settlement are converted into Other Land (i.e., emissions from such conversion are estimated).
[10] 2006 IPCC Guidelines, Volume 4, Chapter 3: Consistent Representation of Land.

Box 6. Land use versus land cover

According to the IPCC guidelines, the reporting of GHGs should be separated by land use categories (based on the six land use classification types). *Land use* refers to the way in which humans use or manage land (e.g., the arrangements, activities, and inputs undertaken); it may also refer to the social and economic purposes for which land is managed. *Land use change* refers to a change in the use or management of land by humans. *Land cover* refers to the biophysical attributes of land (such as whether or not there are trees); it may not always be consistent with the use of the land. In some cases, land use change and land cover change will be identical (e.g., conversion of Forest Land to cropland). In other cases, a change in land cover from Forest to Grassland may reflect a temporary disturbance (e.g., harvest) where the forest is expected to regrow.

The IPCC suggests that land is not fully converted until 20 years after the land use change.[11] If the conversion took place less than 20 years earlier, the land is placed into a conversion category (i.e., is considered in transition), in order to account for the slow change in dead organic matter and soil carbon that occurs when land is converted from one land use to another.

Remote sensing technologies are increasingly used to monitor land cover (and change). Many communities may rely on data derived from satellite imagery to provide activity data for the inventory. Without additional information on land use, however, it is not possible to know whether a land cover change is temporary or permanent.

For community-scale inventories, it may be a reasonable simplification—in the absence of additional data and/or to simplify the GHG inventory for lands—to use land cover as a proxy for activity data and take a "committed" approach to estimating GHGs for forest conversion and disturbances (i.e., to assume full or partial loss of carbon stock at the time of detection and to report the conversion in the year of detection). Doing so will overestimate the actual emissions in the year of detection; however, over time the inventory typically self-corrects.

For example, in the case of a temporary disturbance—such as a forest fire in an area that remains Forest but shows a land cover change from Forest to Grassland in the year of the fire—the GHG inventory may report full carbon stock loss, overestimating the actual loss in the year of the fire (as deadwood decays over time). However, when the forest regenerates, the carbon stock is returned to the reporting. Similarly, if a forest is converted to a developed area, the full change in carbon stock may be reported in the year of conversion, even though in reality soil carbon stock may take years to decay. In addition to simplifying the GHG estimations over time, this method attributes the emissions more closely to the temporal activity that caused it, rather than creating a legacy emission over time.

In contrast, when Forest Land is regenerated (i.e., non-forest converts to forest), it is a reasonable simplification—rather than tracking such lands separately over time (e.g. a 20-year default period)—to assume that after the initial inventory period the removals for this new forest land will be represented by changes in the removal factor estimates that reflect changes in the age-class distribution for all forest land.

[11] The IPCC states that lands remain in a land use change category until the impact of the land use transition on all carbon pools (see Section L.3.1 for a description of carbon pools) is fully realized; the default period is 20 years.

L.2.3 Categories for reporting greenhouse gases from land use

When developing a land use GHG inventory, it is recommended to develop a land use change matrix, with all land included in the inventory analysis period stratified into the six land use classes for the beginning and end of each analysis period, such that all land included in the inventory is assigned to one of 36 possible land use and change categories (Table 5), even if a community initially reports a smaller subset of categories This process is repeated for each inventory analysis period. Once area estimates are combined with appropriate emission/removal factors, values in the individual cells of the matrix represent GHG fluxes from each category.

Table 5. Land use change matrix

	Forest Land	Cropland	Grassland	Wetlands	Settlements	Other
Forest Land	Forest Land remaining Forest Land	Forest Land converted to Cropland	Forest Land converted to Grassland	Forest Land converted to Wetlands	Forest Land converted to Settlements	Forest Land converted to Other Land
Cropland	Cropland converted to Forest Land	Cropland remaining Cropland	Cropland converted to Grassland	Cropland converted to Wetlands	Cropland converted to Settlements	Cropland converted to Other Land
Grassland	Grassland converted to Forest Land	Grassland converted to Cropland	Grassland remaining Grassland	Grassland converted to Wetlands	Grassland converted to Settlements	Grassland converted to Other Land
Wetlands	Wetlands converted to Forest Land	Wetlands converted to Cropland	Wetlands converted to Grassland	Wetlands remaining Wetlands	Wetlands converted to Settlements	Wetlands converted to Other Land
Settlements	Settlements converted to Forest Land	Settlements converted to Cropland	Settlements converted to Grassland	Settlements converted to Wetlands	Settlements remaining Settlements	Settlements converted to Other Land
Other	Other Land converted to Forest Land	Other Land converted to Cropland	Other Land converted to Grassland	Other Land converted to Wetlands	Other Land converted to Settlements	Other Land remaining Other Land

It is recommended to develop, at a minimum, the 6 x 6 land use conversion matrix illustrated in Table 5. Such matrixes can also be expanded to include more subcategories within each broad land category. For example, different forest and/or management types within the Forest Land remaining Forest Land category may be considered based on subcategories that make sense in the context of both local geography and climate action plans. Partitioning the land base into smaller areas has implications for the availability of emission/removal factor data that represent the different land strata.

Even though this Appendix currently covers only Forest Lands (and Trees Outside Forests), in the case of land use change—when forest lands are converted to another land use or when lands are returned to forest lands—knowledge of the pre- and/or post-forest land use will provide more accurate estimates of C stock changes. In addition, guidance may be developed for other land uses and so establishment of a well-defined land base can be useful in the future.

Table 6 describes currently available off-the-shelf data sources for the United States that can be used to create a land use and change matrix. They are elaborated further in the Protocol's Guidance Document.

Table 6. Geospatial data sets available to estimate land cover and change in US communities

Option	Advantages	Disadvantages
National Land Cover Database (NLCD) (www.globalforestwatch.org)	• Only US-specific wall-to-wall land cover dataset at 30-meter resolution. • Available in a consistent time series. • Includes all IPCC land use classes.	• Periodic (not annual).
University of Maryland tree cover change (www.globalforestwatch.org)	• Produced with intent of mapping change in tree cover over time in a globally consistent manner. • Captures extent of tree cover outside Forest Land. • Release of data is annual and timely.	• Does not provide all six IPCC land classes (only tree cover and loss). • Tree cover gain product not updated past 2012. • Less accurate in areas with low tree cover.
Cropland Data Layer (CDL) (https://nassgeodata.gmu.edu/)	• Data are disaggregated into many crop categories. • Includes all IPCC land use classes. • Release of data is annual and timely.	• Produced with intent of mapping annual land cover (not changes in land cover over time). • Classification algorithm does not focus on achieving high accuracy of nonagricultural classes (CDL recommends NLCD for studies involving non-agricultural land cover). • Inconsistencies in processing across states.
Local data	• Categories are tailored to local conditions. • Likely more accurate than national or global products. • Produced by people with local expertise.	• May be produced with intent of mapping land cover and not changes in land cover over time. • May be outdated or incomplete coverage. • May not include all IPCC land use classes.

It is recommended to estimate land-based GHGs by land unit rather than activity—that is, across the entire land area regardless of the variety of actions and/or activities that may occur on such lands. Estimating GHGs in this way helps avoid double-counting of the impacts of a variety of activities that may occur on the same land. For example, both grazing and forest management activities can take place on the same parcel of land. If the land is classified as Forest (given the hierarchy of classifications provided in Section L.2.2), the changes in carbon stock should reflect the impacts of both grazing and forest management.

L.3 General Methods for Estimating Greenhouse Gases from Land Use

This section provides general information applicable to estimating GHG emissions and removals for all land uses. Subsequent sections provide additional guidance for specific land uses.

L.3.1 Carbon pools

A carbon pool, or reservoir, is a component of the climate system (other than the atmosphere) that has the capacity to store, accumulate, or release carbon. For land use, the seven main carbon pools defined by the IPCC and adapted for reporting in the United States include the following:

- *Biomass carbon*: Aboveground and belowground carbon in living plant mass.
    - *Tree biomass*: Live trees with diameter at breast height (DBH) of at least 2.5 cm, including carbon mass of coarse roots greater than 0.2–0.5 cm (published distinctions between fine and coarse roots are not always clear), stems, branches, and foliage.
    - *Understory vegetation:* Live vegetation that includes the roots, stems, branches, and foliage of seedlings (trees less than 2.5 cm DBH), shrubs, and bushes.
- *Dead organic matter:* Carbon in standing dead, downed dead wood, coarse dead roots, and litter pools.
    - *Standing dead trees:* Standing dead trees with DBH of at least 2.5 cm, including carbon mass of coarse roots, stems, and branches.
    - *Down dead wood*: Woody material that includes logging residue and other coarse dead wood on the ground that is larger than 7.5 cm in diameter, as well as stumps and coarse roots of stumps.
    - *Litter*: Dead organic matter transferred from aboveground or belowground live biomass pools on the soil surface or within the soil. In forests, the dead organic matter covering the mineral soil is referred to as *forest floor*; it includes fine woody debris up to 7.5 cm in diameter, tree litter, and fine roots in the organic forest floor layer above mineral soil.
- *Soil organic carbon*: Carbon in soil (i.e., soil organic matter [the decomposition products of microbial organisms or partially decomposed plant material that is smaller than 0.2 cm]).
- *Carbon in harvested wood*: Includes products in use and in landfills (but not recycled wood products or biomass burned for energy capture). Products in use include end-use products that have not been discarded or otherwise destroyed. Examples include residential and nonresidential construction, wooden containers, and paper products. Products in landfills include discarded wood and paper placed in landfills, where most carbon is stored long term and only a small portion of the material is assumed to degrade at a slow rate.

Carbon is transferred among these seven pools and between them and the atmosphere. The amount of carbon in each pool is commonly called a *stock*; transfers are changes in carbon stocks. A decrease in total carbon stock in the terrestrial ecosystem equates to an emission of CO_2 from the terrestrial ecosystem to the atmosphere. An increase in total carbon stock equates to a removal of CO_2 from the atmosphere into the terrestrial ecosystem. Emissions and removals are often referred to as CO_2 fluxes.

It may not be necessary to calculate changes in carbon stocks for all seven pools. For example, if using the production approach (recommended in Section L.4) and no harvesting takes place, there will be no additions of carbon to harvested wood products pools in use or in landfills, although there may be legacy effects of past harvests on GHG emissions that can last for decades (e.g., products still in use and landfills). Also, absent data on soils, it is a reasonable simplification to assume that there are no changes to the soil organic carbon pool for activities that do not disturb the soil, such as a light forest thinning. Additional guidance is provided in Section L.4, Step 3.

L.3.2 Non-CO_2 greenhouse gas emissions

Non-CO_2 GHG emissions refer to methane (CH_4) and nitrous oxide (N_2O) emissions that occur as a result of land use and management activity. They include biomass burning from prescribed fire (controlled burn) or wildfires, nitrogen (N) management practices on managed soils, livestock management, rice cultivation, and wetland management.

In the case of prescribed fire or wildfires, oxidation of biomass releases CO_2, CH_4, N_2O, and other precursors that later form greenhouse gases—namely, CO_2, CH_4, carbon monoxide (CO), non-methane volatile organic compounds (NMVOCS), N_2O, and nitrogen oxides (NO_x). The CO_2 emissions are factored into the calculation of carbon stock changes for the pools that are oxidized and therefore do not need to be estimated as part of the non-CO_2 greenhouse gas emissions (doing so would lead to double counting of emissions). The volumes of the other gases are estimated to determine the impact of biomass burning on anthropogenic GHG emissions if the fire occurs on managed land.

N management is common in many land uses, particularly Croplands but also Forest Lands in some regions. It leads to direct and indirect soil N_2O emissions. Management activities include synthetic fertilizer additions, organic amendments such as manure, and N additions in dead organic matter. Enhancement of soil organic matter mineralization as a result of management activity is also considered a source of N additions that leads to anthropogenic emissions of N_2O.

Rice cultivation in flooded conditions can generate significant CH_4 emissions; it should be classified as part of the land representation analysis but is often included in the reporting for the agriculture sector. Communities need to assess rice cultivation as part of their land representation regardless of the sector in which the emissions are reported. The calculation of emissions will depend on land use and land use change data as well as water management practices, organic amendment practices, soil type, and cultivar selection. (Livestock management is covered in the agriculture appendix and is not discussed here.)

All wetlands sequester carbon and are a source of GHGs. Non-CO_2 emissions primarily involve CH_4 and N_2O. These emissions are highly influenced by land use and management practices, vegetation, soil organisms, chemical and physical soil properties, geomorphology, and climate. The production and consumption of carbon in wetland-dominated landscapes are important for estimating the emissions of CH_4, and N_2O to the atmosphere. The US Department of Agriculture (USDA) recommends using a biogeochemical process model to estimate these emissions, which are highly dependent on activity data on management of vegetation, water, soil, and fertilization (Ogle et al. 2014).

L.3.3 Calculating greenhouse gas emissions and removals from land use

When estimating GHG emissions for other sectors, a general equation is applied in which activity data are multiplied by an emissions factor to estimate GHG emissions. For land use, both emissions and removals can occur, so the net total GHG flux (which can be positive or negative) is represented as the summation of the GHG emissions and removals from all areas of land.

The approach summarized below represents a simplification of the “gain-loss” method described by IPCC and often used in national GHG inventories. The full IPCC gain-loss method is presented in the annex, which communities may want to apply if the required data are available. For the simplified gain-loss method, both gains (GHG removals from the atmosphere) and losses (GHG emissions to the atmosphere) are represented by activity data multiplied by emission factors:

$$Net\ GHG\ Flux = GHG\ emissions + GHG\ removals \qquad \text{(Eq. 1)}$$

$$GHG\ emissions = \sum_{land} AD \times EF$$

$$GHG\ removals = \sum_{land} AD \times RF$$

where, in most (but not all) cases, activity data (AD) are expressed in units of land area (hectares) over which an activity has occurred, and emission factors (EF) or removal factors (RF) are the annual change in CO_2e per area.

L.4 Forest Land

This method allows a community to develop GHG estimates for three forest categories: Forest Land Remaining Forest Land (standing forests), Forest Land Converted to Non-Forest (forest loss or deforestation), and Non-Forest Converted to Forest Land (afforestation or reforestation). The method breaks down the process into seven steps:

Recommended Approach: Estimate forest-related GHGs using the following steps:

Step 1: Consider the need for further stratification.

Step 2: Determine areas of forest-related land use and change over the inventory analysis period (activity data, disaggregated by strata and substrata as appropriate).

Step 3: Determine the appropriate emission and removal factors for Forest Land use and change categories (disaggregated by strata and substrata as appropriate).

Step 4: Calculate carbon stock changes from Forest Land and forest-related land use transitions.

Step 5: Calculate non-CO_2 emissions from Forest Land if appropriate and convert into units of CO_2e.

Step 6: Determine whether to include harvested wood products in the inventory; calculate carbon stock changes in the harvested wood product pool if appropriate.

Step 7: Estimate total net GHG flux from forests over the inventory analysis period, and annualize the result into units of tCO_2e/yr.

In the United States, agencies of the federal government and many states provide nationally or statewide consistent databases, data repositories, and formats relevant to these steps. The methods described below and in the Guidance Document to this appendix recommend a combination of data sources that are most widely applicable to communities across the United States. If high-quality and more locally appropriate data are available for a community, their use is encouraged. In all cases, the methodologies and data sources applied should be disclosed wherever the results are published.

Step 1: Consider the need for further stratification.

A community may wish to disaggregate the total area of Forest Land included in the inventory into smaller units, or strata, either for reporting purposes or because estimates of carbon density (carbon per unit area) or forest carbon increment values (carbon sequestered per unit area per unit time) may vary significantly across strata, influencing the final emission or removal factor applied. Stratification is more likely to be necessary when carbon stock densities are highly variable or activities have highly variable impacts on carbon stocks.

Stratification of a community's Forest Land can be achieved by spatially intersecting maps of forest cover with other relevant datasets. Stratification by percentage canopy cover in forest areas is consistent with the federal GHG inventory. Stratification can also be based on ecological factors, such as climate, soil, or vegetation type, and/or on management factors such as forest ownership or forest use. Additional stratification potentially reduces uncertainties in the resulting GHG flux estimate. This advantage must be weighed against the disadvantage of adding complexity to the GHG estimation process. Communities with diverse types of forests and forest management practices within their inventory's land base may consider additional stratification of the Forest Land use category (e.g., where Forest Land is mountainous; subject to different management regimes, such as plantation forestry versus wilderness areas; or forest stands vary considerably in age or hydrological regime). If a community has relatively homogenous forests, has limited information about how forest carbon density varies over the landscape, or is not considering additional substrata (for other reasons, such as informing policies [see Box 7]), it may wish to apply average emission or removal factors for all Forest Land included in the inventory.

Box 7. Developing data useful for Climate Action

For the purposes of *using* the data beyond a GHG inventory estimate—for example, to support the development of climate mitigation actions—it may be also be useful to consider stratifying forest land data in ways that inform intended actions. For example, land may be separated by authority (e.g. federal, state, and community managed lands or public versus private lands) or by management practice (e.g. conservation or protected areas versus forest plantations). Doing so can help to track the GHG impact of various activities within a community's climate action plan.

There is no single correct way to stratify land. Stratification procedures are designed primarily with the goal of minimizing uncertainty and error within strata by assigning the most applicable emission and removal factors or focusing attention on specific land areas of interest to the community. The simplest option (no stratification, i.e., all forest land is treated as a homogenous unit) may be best if data are lacking. However, it may still be important to stratify for reporting purposes; in these cases, the same emission or removal factors can be used for multiple strata.

Step 2. Determine areas of forest-related land use and change over the inventory analysis period

The next step in preparing the GHG inventory for Forest Land is to assemble the data on the magnitude of human activity resulting in emissions or removals taking place during a given period. Reporting categories are defined by the Forest Land use and change shown in Table 7 (the blue boxes). They may be further disaggregated into subcategories, as appropriate. Generating relevant activity data involves obtaining area estimates for each of the categories (blue boxes) highlighted in Table 7, which are generally derived from land cover maps that contain the community's land base. Once the decision has been made about which source of land cover map to use, estimates can be generated by a qualified GIS technician, following instructions provided in this protocol's companion Guidance Document.

Table 7. Relevant categories within the land use conversion matrix for reporting on Forest Land

	Forest Land	Cropland	Grassland	Wetlands	Settlements	Other
Forest Land	Forest Remaining Forest	Forest Converted to Cropland	Forest Converted to Grassland	Forest Converted to Wetlands	Forest Converted to Settlements	Forest Converted to Other Land
Cropland	Cropland Converted to Forest	Cropland Remaining Cropland	Cropland Converted to Grassland	Cropland Converted to Wetlands	Cropland Converted to Settlements	Cropland Converted to Other Land
Grassland	Grassland Converted to Forest	Grassland Converted to Cropland	Grassland Remaining Grassland	Grassland Converted to Wetlands	Grassland Converted to Settlements	Grassland Converted to Other Land
Wetlands	Wetlands Converted to Forest	Wetlands Converted to Cropland	Wetlands Converted to Grassland	Wetlands Remaining Wetlands	Wetlands Converted to Settlements	Wetlands Converted to Other Land
Settlements	Settlements Converted to Forest	Settlements Converted to Cropland	Settlements Converted to Grassland	Settlements Converted to Wetlands	Settlements Remaining Settlements	Settlements Converted to Other Land
Other	Other Land Converted to Forest	Other Land Converted to Cropland	Other Land Converted to Grassland	Other Land Converted to Wetlands	Other Land Converted to Settlements	Other Land Remaining Other Land

Activity data may also involve other types and sources of data beyond land cover maps. For example, forest management practices that affect GHGs in the Forest Remaining Forest category may include data and/or maps on the extent and location of timber harvesting, prescribed fire, thinning and other stocking control practices, or fertilization.

Activity data need to be matched with appropriate emissions and removal factors (Step 3). As data are compiled and evaluated, it may be necessary to iterate across Steps 1, 2, and 3 before arriving at the most appropriate way to match land areas with emission and removal factors.

In some instances, a community preparing activity data for Forest Land may apply the assumption that any observed change in Forest Land cover corresponds to a change in land use. However, as discussed in Box 6, on land use versus land cover, inferring land use from land cover could result in placing GHG estimates into the wrong land use reporting category. Therefore, it is recommended that supplementary data and information be used to first test the assumption that an observed change in forest cover during the inventory analysis period does in fact correspond to a change in land use. This can be done using a combination of local knowledge/expert judgment, site visits, and/or high-resolution satellite or aerial imagery from the year the change was observed. In addition, spatial overlays of Forest Land use areas (e.g., areas designated as national, state, or local forest or park areas or managed forest areas); areas of natural disturbances; or planned urban expansion areas can support improving the attribution of land cover change to the correct reporting categories.

Where a community stratifies its Forest Land into subcategories, emission or removal factors specific to additional strata may not be available. However, a community may wish to track and report on such lands for policy or other purposes and may simply apply the same emission and removal factors to multiple strata.

Step 3. Determine the appropriate emission and removal factors for all land use and change categories (disaggregated by substrata if appropriate)

There are many sources of data for calculating emission and removal factors, as well as precompiled emissions and removal factors that can be readily applied to the inventory. Table 8 summarizes these data sources (the companion Guidance Document provides more details on them). Using prepared look-up tables, on-line models, and calculation tools will simplify the process. It is recommended that data specific to the inventory area be used to estimate emissions and removal factors.

Table 8. Data sources available for estimating emission and removal factors in US forests

Data source	Advantages	Disadvantages
US Forest Service Forest Inventory and Analysis (FIA) plots (https://www.fia.fs.fed.us/forestcarbon/index.php)	• Data are readily available, of high quality, and measured annually. • Nonbiomass pools are estimated.	• Few measured plots over a small community area are not likely to be statistically representative. • Plots may have been measured long ago.
Forest carbon density maps for biomass and other carbon pools	• Wall-to-wall coverage leads to easier stratification and summarization of GHGs for different forest areas within the community.	• Requires GIS expertise to use. • Uncertainty at pixel scale is usually high. • Often covers only aboveground biomass carbon pool.

	• Allows co-location of estimates of emission factors with locations of disturbance/loss.	• May be derived from sparse plot data that may have been measured long ago.
Local forest inventory data collected by the community or other entity (e.g., the state)	• Locally appropriate allometry applied. • May cover both forest and non-forest areas.	• May not be statistically representative. • Local standards and protocols may diverge from national ones.

Emission and removal factors are highly dependent on the nature of the activity. For example, a deforestation event will have a large initial pulse of emissions that occurs at the time of the event, whereas afforestation or forest growth within undisturbed stands will have a much smaller removal factor applied over many years or decades as the forest grows. For each activity, communities need to choose a time frame over which the factor applies. The time frame can be annual or multiple years. As described earlier (Box 6), it may be simpler to take a "committed" approach to estimating changes in carbon stocks, particularly for conversion (i.e. forest land to non-forest) or losses associated with disturbances, by assuming full or partial loss of C stock at the time of detection. In other words, the "committed approach" estimates the expected future losses in carbon stock and assigns it to the year of detection. This will overestimate the actual emissions in the year of detection, but over time the inventory should self-correct.

For the case of removals associated with conversion of non-forest to Forest Land, a simplification would be to apply a removal factor associated with younger stands for the initial inventory period and to assume that the start date for the new stand is the beginning of the inventory period (based on the lag in detection of new forests). Thereafter, the stand would be placed within the Forest Land Remaining Forest Land category under the assumption that average annual removals for this category are captured within the new age-class distribution of forests within the community.

Emission and removal factors should represent the changes in carbon stocks for all seven main carbon pools if they are significantly affected by the activity. However, it is common practice to ignore very small changes in selected carbon pools (e.g., less than 3 percent of the total change in all carbon pools) because such small changes can be challenging to measure or estimate, particularly for soil carbon.

This section describes an approach in which changes in all carbon pools are summed into either a single removal factor associated with land that has been undisturbed during the inventory analysis period (no stand-replacing disturbance) or an emission factor, in the case of land that has had a significant disturbance. Within either of these broad categories, some carbon pools may increase and some may decrease, based on the typical transfers among carbon pools that occur in both disturbed and undisturbed forests. (For inventory compilers interested in delving deeper into the changes in individual carbon pools, equations in the annex represent the complete gain-loss approach as defined by the IPCC.)

Ideally, emission and removal factors are estimated from data that represent the forest strata defined for the GHG inventory, if applicable (see Step 1). Because data may be lacking for certain areas, combining strata or extending the area beyond that of the GHG inventory area (see Section L.2.1) may be necessary for calculating emission and removal factors. For example, a community may be interested in separate GHG reporting for three different ownership groups (e.g., federal, state, and locally owned forests) but be able to estimate emission and removal factors only for all groups combined. As another example, there may be interest in a specific forest type, but insufficient data about that forest type within the inventory area may require the use of data about that forest type from a larger geographic area that closely resembles the inventory area.

The availability of data for calculating emission and removal factors is likely to be different for different land use categories and carbon pools. Representative data on how carbon stocks are affected by conversion of Forest Land to other land-use categories are often lacking; therefore, we highlight here a set of assumptions that may be used to help estimate the changes in carbon stocks for forest land conversions (Table 9). However, it may be possible to use additional data (e.g. beyond the NLCD) to refine these assumptions. Alternatively, if a community has local data about losses of carbon associated with Forest Land conversion, they, rather than the generic estimates provided in Table 9, should be used. For additional examples of how to handle these types of situations, see the companion Guidance Document.

Table 9. Defaults for estimating percentage losses of C for Forest Land Conversion to other land uses.

Note: Biomass, dead organic matter and soil C losses may be restored with conversion back to Forest Land, but the time dynamics are typically longer than 20 years. These estimated percentage losses should be applied to estimates of C stocks on the land prior to conversion.

	Forest converted to Cropland	Forest converted to Grassland	Forest converted to Wetlands	Forest converted to Settlements	Forest converted to Other land
Biomass C[a]	100%	50% in the Western US, 100% otherwise	100%	100%	100%
Dead Organic Matter C	100%	100%	100%	100%	100%
Soil Organic C[b]	23%	0%	0%	30%	100%

[a] Biomass C loss for Forest Land converted to Grassland is based on assumptions developed for the US National Greenhouse Gas Inventory. Land post-deforestation may retain significant biomass upon conversion from forest; if a community has information on tree cover within the post-deforestation land use category, for example, these default percentages may be adjusted.

[b] Soil organic C loss is based on factors used in the US National Greenhouse Gas Inventory. Local practices regarding topsoil and lawn care may indicate the need for a different estimate. The estimate for Cropland is based on aggregated value across all climates in the United States.

Step 4. Calculate change in C stocks (CO_2 emissions and/or removals) from forest land and forest-related land use transitions

This step covers the estimation of changes in C stocks (CO_2 emissions and removals) for Forest Land Remaining Forest Land as well as land that converts between forest and non-forest during the inventory analysis period. Each equation estimates the change in carbon stock as the product of the appropriate activity data and the appropriate emission/removal factor.

Step 4.1 Calculate change in C stocks from forest land remaining forest land (ΔC_{FRF})

This refers to Forest Land that did not change land use during the period of analysis. It includes areas that may have been subject to tree harvest for commercial or other purposes or other type of disturbance during the inventory period but that are still considered Forest Land Remaining Forest Land from a land use perspective. The GHG flux reflects the *net balance* of emissions and removals, both of which can occur simultaneously in Forest Land Remaining Forest Land in different areas and/or at different times during the inventory analysis period. In the case of Forest Land remaining Forest Land, it is most transparent to estimate carbon gains and carbon losses separately and to then calculate the net balance between the two fluxes.

The simplified gain-loss method defines two general cases of Forest Land Remaining Forest Land: undisturbed and disturbed. For relatively undisturbed Forest Land (including land that may have experienced very minor disturbances), carbon stock changes (CO_2 removals) are estimated as the area of undisturbed Forest Land in each stratum (as appropriate) over the inventory period multiplied by the appropriate removal factor for that stratum and the number of years in the inventory analysis period.

For disturbed forests, carbon stock changes (CO_2 emissions) are estimated as the area of disturbance in each stratum over the inventory period multiplied by the appropriate emission factor for that stratum. Determining the appropriate emission factors can be complicated, because different types and severities result in different levels of emissions (and removals) that vary over time since the disturbance. For severe disturbances that may affect up to 100 percent of the canopy, there may be a large pulse of emissions at the time of disturbance, followed by continuing emissions as dead trees and detritus decompose and lose their stored carbon. At the same time, vegetation may be regrowing, such that removals will be increasing. The balance of these emissions and removals typically results in net emissions that last for one or several decades for severe disturbances. For less severe disturbances, removals from regrowth may exceed emissions from the disturbance, such that after a few years or a decade, the disturbed forest once again experiences net removal of CO_2.

To simplify the accounting, we recommend using a committed approach by estimating the net change in carbon stocks (emission or removal) over 20 years and applying this factor to the area of disturbance during the inventory period. The estimate should reflect both the type and severity of disturbance. All estimates should be converted to average annual estimates as a final calculation step, if necessary (see Step 7).

$$\Delta C_{FRF} = \Delta C_{undisturbed} + \Delta C_{disturbed} \qquad \text{(Eq. 2)}$$

$$\Delta C_{undisturbed} = \sum_{i=1}^{n} (AD_i \times RF_i \times T)$$

$$\Delta C_{disturbed} = \sum_{i=1}^{n} \sum_{j=1}^{J} (AD_{ij} \times EF_{ij})$$

where

ΔC_{FRF} = change in carbon stocks in Forest Land Remaining Forest Land over the inventory period (tC)

$\Delta C_{undisturbed}$ = change in carbon stocks in undisturbed Forest Land Remaining Forest Land over the inventory period (tC)

$\Delta C_{disturbed}$ = change in carbon stocks in disturbed Forest Land Remaining Forest Land over the inventory period (tC)

AD_{ij} = area of Forest Land in stratum *i* (of disturbance type *j*, if applicable) (hectares)

i = 1, 2, 3, …, *n* forest strata

j = 1, 2, 3, … , *J* disturbance types

T= number of years in inventory analysis period

EF_{ij} = emission factor for each disturbance type *j* in stratum *i* (tC/hectare)

RF_i = removal factor for each stratum *i* (tC/hectare/year) (average annual removal factor)

Substantial data are available for estimating disturbance impacts from the most common disturbance events occurring in the United States (fire, insects, harvesting, and wind). Emission factors can thus be calculated for different forest types, disturbance types, and disturbance severities (EF_{ij}). The US Forest Service has calculated the effects of main disturbances on carbon pools for the main forest and disturbance types for national forests by region (Birdsey et al. 2019; Raymond et al. 2015). For more information on estimating disturbance impacts, see the accompanying Guidance Document.

Sample calculation 1 estimates the change in carbon stocks for two forest types in a community—one that has been disturbed during the inventory analysis period and one that has not.

Sample calculation 1. Estimating the change in carbon stocks for Forest Land Remaining Forest Land using the simplified gain-loss method

This example is for an area in a hypothetical county in the southeastern United States containing two forest types having an average age of 45 years. It uses the simplified committed approach to estimate emissions from disturbances. A negative number indicates net removal (gain) of CO_2 from the atmosphere; a positive number indicates net emissions (loss) of CO_2 to the atmosphere. Units are metric tons of carbon (= $CO_2e/3.67$).

Data:

Stratum 1: Forest type 1 undisturbed, area = 80 hectares

Stratum 2: Forest type 1 disturbed (75 percent severity), area = 20 hectares

Stratum 3: Forest type 2 undisturbed, area = 200 hectares

Stratum 1: Removal factor = -1.46 tC per hectare per year

Stratum 2: Emission factor = 78.3 tC per hectare

Stratum 3: Removal factor = -2.24 tC per hectare per year

Calculations:

Stratum 1 gain = -1.46 x 80 x 5 = -584 tC

Stratum 2 loss = 78.3 x 20 = 1,566 tC

Stratum 3 gain = -2.24 x 200 x 5 = - 2,240 metric tC per year

Net GHG flux = 1,566 + (-584 – 2,240) tC = -1,258 tC (for the five-year period)

Box 8. The "stock change" method

Most communities will use the approach outlined above (i.e. the simplified gain-loss method) to estimate GHGs from Forest Land Remaining Forest Land. Another method is called the stock-change approach and can be used where sufficient permanent, remeasured forest inventory sample plots are available in or near the community to characterize the strata of interest. As a rule of thumb, roughly 20 remeasured sample plots are needed per stratum to use the stock-change method, unless the forest is highly uniform in nature (Pearson et al. 2007). Calculations are repeated for each additional stratum of interest, as defined by the activity data and any other classification variable of interest as determined by activity data, a map, or statistical reference, such as forest type.

The stock change method may not explicitly account for disturbances unless disturbed areas are defined as strata. In other words, the sample plots within a stratum may represent both undisturbed and disturbed areas. This would be the case if, for example, one were to base an estimate on all of the sample plots in a stratum without separating undisturbed and disturbed areas into distinct strata in order to estimate the overall change in carbon stocks. Additional calculations may be needed to explicitly estimate effects of disturbances if using the stock-change method. Separate estimates of impacts of disturbances after calculating the overall changes in carbon stocks are not additive. The entire stock-change calculation will inherently account for these disturbances; the additional calculations are thus necessary only in order to understand what portion of the overall stock change in the forest is attributable to certain disturbances.

Step 4.2 Calculate change in carbon stocks from Forest Land Converted to Non-Forest Land ($\Delta C_{F \rightarrow NF}$)

This is forest land that changed land use during the period of analysis; if it occurs, forest clearing is likely to be one of the largest sources of GHG emissions from forests during the inventory period. For Forest Land Converted to Non-Forest Land, carbon stock changes (CO_2 emissions) are estimated as the area of conversion in each stratum over the inventory analysis period multiplied by the appropriate emission factor for that stratum.

$$\Delta C_{F \rightarrow NF} = \sum_{i=1}^{n} \sum_{k=1}^{K} AD_{ik} \times EF_{ik} \qquad \text{(Eq. 3)}$$

where

$\Delta C_{F \rightarrow NF}$ = change in carbon stocks in Forest Land Converted to Non-Forest Land over the inventory period (tC)

AD_{ik}= area of forest stratum *i* converted to non-forest category *k* (hectares)

EF_{ik}= emission factor for each forest stratum *i* converted to non-forest category *k* (tC/hectare)

i = 1, 2, 3…*n* forest strata

k = 1, 2, 3…*K* non-Forest Land categories (i.e., Cropland, Settlement, Grassland, Wetland, Other Land).

For estimating emission factors, the conversion of Forests to other land uses immediately reduces the stock of carbon in both living biomass and dead organic matter. Over time, soil carbon may be reduced in some cases, particularly upon conversion to Croplands or Settlements; other conversions may lead to limited change in soil carbon stock or even an increase, such as conversion to Grassland or Wetlands (see Table 9). Regardless, the conversion of Forest Land to other land uses is likely to reduce the overall long-term carbon storage potential of the land. Some of the biomass may also be removed from the site and converted into forest products, such as lumber, paper, pulp, and other products that have longer-term but variable decomposition rates—and hence longer-term and variable emissions over time (see Step 6 below on harvested wood products). All of these changes in carbon stocks for various pools should be estimated when determining the changes in carbon stocks (the emission factor).

The most important activity data to collect are the area and rates of forest clearing for each stratum and, if possible, the land category that Forest Land was converted to, which will help identify the appropriate emission factors to apply (Table 9). To estimate emissions, it is also necessary to estimate the characteristics of the stratum before clearing, including the biomass, dead organic matter, and soil organic carbon of the site. If predisturbance estimates of carbon stocks are not locally available for transitions from Forest to other land uses, it is recommended to use regional averages for above-ground biomass and other carbon pools and their fractional disposition, which are available from published sources (see the Guidance Document). The default emission factors in Table 9 may be modified with additional information. For example, if some live trees are left standing on the site after conversion, the loss of biomass would be less than 100 percent. It may also be important to estimate the fraction of the aboveground biomass that was burned following a fire and the fraction that was removed in the form of wood products. Likewise, the fraction that remains in the dead organic matter and soil carbon pools may be locally different than represented in Table 9.

Sample calculation 2 estimates the change in carbon stock for Forest Land Converted to other land uses. This calculation would be repeated for each forest stratum of interest *i* converted to non-Forest Land category *k*. Step 6 describes the calculation for carbon in harvested wood products.

Sample calculation 2. Estimating the change in carbon stocks for Forest Land Converted to other land
Carbon stocks for some pools may continue to change after the first year. They can be estimated as if they occurred in the first year using the committed approach (recommended) or tracked over time using the methods described for Forest Land Remaining Forest Land.
The example described here is for an area in a hypothetical county in the southeastern United States that is converted from an oak-hickory forest to a parking lot (all impacts on carbon stocks would occur initially and not over time in this case). The calculation for only one forest type is shown, using the committed approach.
Data:
Stratum 1: Forest type 1 area = 100 hectares
Forest type 1 emission factor = 83.7 tC per hectare
Calculation:
Change in carbon stock = 83.7 x 100 = 8,370 tC (over the five-year inventory period)

Step 4.3 Calculate change in carbon stocks from Non-Forest Land Converted to Forest Land

This is non-forest land that changed to forest land over the period of analysis. For non-Forest Land converted to Forest Land, carbon stock changes (CO_2 removals) are estimated as the area of forest gain over the inventory period multiplied by the appropriate removal factor.

$$\Delta C_{NF \rightarrow F} = \sum_{i=1}^{n} \sum_{k=1}^{K} AD_{ki} \times RF_{ki} \times T \quad \text{(Eq. 4)}$$

where

$\Delta C_{NF \rightarrow F}$ = change in carbon stocks in non-Forest Land converted to Forest Land over the inventory period (tC)

i = 1, 2, 3…*n* forest strata

k = 1, 2, 3…*K* non-Forest Land categories

AD_{ki} = area of non-forest category *k* converted to forest strata *i* (hectares)

RF_{ki} = removal factor for each non-forest category k to forest category *i* (tC/hectare/year) (annual average removal factor over inventory analysis period)

T= number of years since the conversion; if unknown (i.e. when in the inventory analysis period the conversion took place), then it is suggested to use the inventory period[12]; years

A parcel of non-Forest Land can be converted to forest, plantation, or other treed landscape through intentional planting or natural regeneration. Step 4.3 applies to land that is not currently Forest Land; it does not include Forest Land that is regenerated after harvest as part of forest management (although the estimation approach would be the same). When estimating activity data, it is good practice to distinguish between a land use change and a land cover change, which may be classified more appropriately as forest regeneration after harvest or natural disturbance, which is associated with Forest Land Remaining Forest Land (Box 9).

Box 9. Defining land use change from non-forest to Forest Land

The terms *afforestation*, *reforestation*, and *regeneration* refer to establishing a forest where trees were formerly not present. How these terms are defined affects the estimation of changes in carbon stocks. This protocol uses the terms *afforestation* and *reforestation* to designate a land use change; the term *regeneration* is associated with the management of Forests Remaining Forests. *Afforestation* is generally used to define instances of land use change from non-forest to Forest where the area has not been classified as forest for an extended period (at least 50 years) or was never classified as forest and is planted, seeded, or allowed to naturally regenerate to establish Forest Land. *Reforestation* involves land that was originally forested, then converted to nonforest, and then changed back from nonforest to forest after having been deforested for an extended period (50 years or less).

Afforestation and *reforestation* are often distinguished from one another because changes in soil carbon may be different. To simplify the estimation process and because historical land use data are often lacking, this appendix does not distinguish between these two terms; both are considered a land use change and treated the same way. In contrast, *regeneration* refers to Forest Land that has been temporarily destocked of trees as a result of harvesting or disturbance events with the expectation that these areas will become stocked again by trees that are planted, seeded, or allowed to naturally regenerate. These areas should be considered as Forest Land Remaining Forest Land rather than counted as a land use change. It is important to consider these terms in the context of understanding the difference between land cover and land use (see Box 6). In practice, if land cover maps are used to classify land, detection of tree canopy cover associated with afforestation, reforestation, or regeneration may occur some years after establishment, so reporting of the carbon stock changes may be delayed.

Note: This box is consistent with Hoover et al. (2014).

Initially, Non-Forest Land Converted to Forest Land can be identified as a new stratum (or multiple strata if different practices or tree species are established). These additional strata may be tracked separately or merged with other forest strata with similar characteristics.

For land that converts from non-forest to Forest, the stock of carbon in biomass and dead organic matter generally increases over time but at varying rates as the new forest is established. Biomass increases predictably as forests grow. Soil organic carbon also changes, but in less predictable ways. For instance, establishing a forest plantation on grassland in cool temperate regions may result in an initial and temporary loss of soil carbon before it builds up again. Removal factors should reflect the variability of changes in stocks of carbon over time. For example, a community may choose to apply one factor

[12] We recommend using the inventory period as a default because of the typical lag in detection of new forests when using remote sensing methods (see Step 3 explanation).

representing the first 10 years of growth, when biomass accumulation is relatively slow; a different factor representing years 10–30, when trees are accumulating biomass at a faster rate; and a third factor that represents the slower growth of the maturing forest. It is also possible to use an average removal factor over the lifetime of the new forest, recognizing that this selection would mask the variability of actual carbon removal over time. The Guidance Document provides additional recommendations for selecting removal factors for regrowing Forest Land.

For plantations, basic information on site preparation, species selection, and densities of plantings can be used with a projection of the long-term plan for the site to make a reasonable estimation of changes in carbon stocks. If natural regeneration is the primary means of establishment, seedling counts can be used to develop a growth projection or regional yield tables can be used to estimate projected stocks. The prior use and management of the stratum or land use should also be documented, as the historical use of the land affects carbon stock and stock change estimates, particularly for soil carbon. For instance, establishment of a forest stand on a former grassland will have a different result in terms of carbon sequestration than establishment on a former agricultural field planted with row crops.

Sample calculation 3 estimates the change in carbon stock for non-Forest Land Converted to Forest Land. This calculation would be repeated for each non-Forest Land category of interest (*k*) converted to forest stratum of interest *l*, as defined by the activity data and any other classification variable determined by a map or statistical reference, such as forest type.

Sample calculation 3. Estimating the change in carbon stocks for non-Forest Land Converted to Forest Land

This example is for an area in a hypothetical community that is converted to a pine plantation. The calculation for only one forest type is shown. In this example, the year (over the five-year inventory analysis period) the regrowth occurred is not known.

Data:

Stratum 1: Forest type 1 area = 100 hectares

Forest type 1 net growth (removal factor) = -0.86 tC per hectare per year

Calculation:

Change in carbon stock = -0.86 x 100 x 2.5 years = -215 tC (for the five-year period)

Step 5. Calculate non-CO_2 emissions from Forest Land if appropriate

The main sources of non-CO_2 emissions from Forest Lands include (a) CH_4 and N_2O from biomass burning during prescribed fire or wildfires and (b) soil N_2O emissions with mineral fertilization and organic amendments. Other emissions may also occur, such as CH_4 from forested wetlands. Guidance on these emissions is not provided, because they are typically minor sources in most communities.

Step 5a. Estimate non-CO_2 emissions from biomass burning using equation A.11 in the annex

The area of Forest Lands that is burned may be available from satellite observations or local mapping of fire extents. The biomass stock for the area could be based on data compiled to estimate biomass carbon stocks for disturbances (see Step 3). The emission factors, EF_{CH4} and EF_{N2O}, may be based on the values in the 2006 IPCC guidelines (IPCC 2006). For temperate Forest Lands, the values are 4.7 ± 1.9 kg CH_4 per metric ton of biomass burned and 0.26 ± 0.07 kg N_2O per metric ton of biomass burned.

Step 5b. Estimate direct and indirect soil N_2O emissions using equations A.12–A.16 in the annex

Synthetic fertilizer application data may be available from sales data in the community, or it may be possible to compile them from survey records. Application of organic amendments may be more challenging to compile, particularly if there is a large proportion of manure amendments from livestock farms in the area. IPCC (2006) provides methods for estimating manure production that could be used to approximate the amount of manure N available for application to soils. These methods require data on the livestock population in the county and the manure management systems. The N content of fertilizers is available from fertilizer handbooks or manufacturing data. Manure N content depends on the livestock type; values are provided in the *Agricultural Waste Management Field Handbook* (USDA 1996).

The emission factors can be based on values provided in the 2006 IPCC guidelines (IPCC 2006). They can also be based on state-level estimates of implied emission factors from the US National Greenhouse Gas Inventory (US EPA 2019).

Step 6. Calculate carbon stock changes in the harvested wood product pool (if appropriate)

Harvested wood products temporarily store carbon from the forest ecosystem as the wood goes through a series of production processes and end-uses, with eventual disposal (and emission to the atmosphere). The delay represents a net benefit to the atmosphere. The period of storage varies from long-lived solid wood products that remain in use for long periods of time to products that are quickly disposed of in landfills.

GHG estimation involves (a) estimating the carbon that is temporarily stored in wood products; (b) estimating the carbon temporarily stored in solid waste disposal (SWD) sites, mainly landfills; and (c) estimating the GHG benefits that may occur from using wood instead of other energy sources or materials (the "substitution effect," which is mentioned here for reference but is outside the scope of this appendix).

This step describes the approaches for estimating carbon additions to and losses from the stock of harvested wood products; detailed calculation methods are not provided, because of their complexity and availability in other references. The companion Guidance Document describes several estimation tools that can be used for these calculations and the required input data about harvested wood and type of product, which are often readily available. Biomass that enters into the waste stream is included in Appendix F.

The most common method used to estimate GHGs from harvested wood products is called the production approach.[13] It tracks carbon in wood that was harvested in the area of interest (i.e., boundaries used for the GHG inventory [see Section L.2.1]), regardless of where the wood is consumed.

The guidance provided here is intended to help practitioners estimate changes in carbon in harvested wood using the production approach for two optional accounting methods: (a) estimating the average amount of carbon from the current year's harvest that remains stored in end-uses and landfills over the subsequent 100 years (Hoover et al. 2014) and (b) estimating annual changes in the carbon stored in harvested wood products, accounting for prior year harvests through the current year's harvest

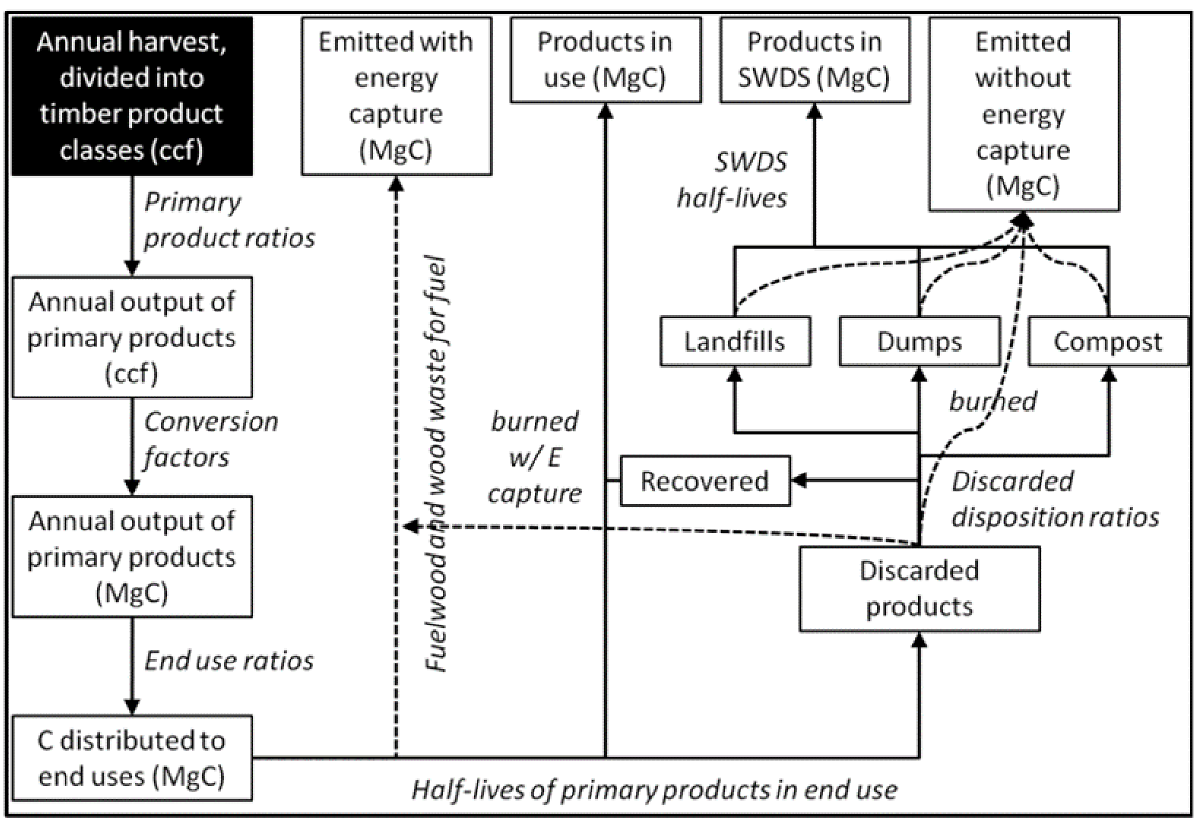
---

[13] An alternative is known as the consumption approach, which involves a similar set of calculations as the production approach, except the starting point is the quantity of different wood products consumed within the boundaries of the inventory area, regardless of where the wood was harvested. The production approach is recommended in this appendix because of data availability for most communities, as well as consistency with the US GHG inventory (which reports to the UNFCCC based on the production approach).

(Stockman et al. 2014). The intent of option 1 is to approximate the average annual climate benefit of withholding carbon from the atmosphere by a certain amount each year for 100 years, as described by a "decay" curve. This average benefit is one that can be credited in the year of harvest, obviating the need to keep track of each year's (or period's) harvested carbon indefinitely. The intent of option 2 is to credit cumulative changes in harvested wood products from past harvests, accounting for the fact that it takes a long time for the carbon in harvested wood products to return to the atmosphere. Option 2 requires much more detailed and continuous accounting over time, as well as data on harvest quantities and types of wood products produced over at least several decades in the past.

Figure 1 shows the calculations that track carbon in harvested wood through four different "fates," from harvest to timber products to primary wood products to end-use to disposal, applying best estimates for product ratios and half-lives at each stage. These calculations form the basis of both approaches described above. Harvest records are used to distribute annual cut volumes among specific timber product classes (e.g., softwood ties, softwood sawlogs, softwood pulpwood, softwood poles, softwood fuel wood, softwood non-saw, etc.). Timber products are further distributed to specific primary wood products (e.g., softwood lumber, softwood plywood, softwood mill residue used for nonstructural panels, etc.) using default average primary product ratios from national level accounting that describe primary products output according to regional forest industry structure (Smith et al. 2006, Appendix A) or, alternately, local data. Box 10 lists the data requirements outlined in Figure 1.

Figure 1. Schematic of approach to quantifying storage and emissions of harvested wood products



Source: Reproduced from Stockman et al. 2014. Ccf = 100 cubic feet, MgC = Megagrams of carbon, SWDS = solid waste disposal sites.

Box 10. Estimating the carbon in harvested wood products

Using the production approach to estimate the carbon in harvested wood products requires the following data (this example uses the annual accounting method. If the average accounting method, only the current year's data are needed):

- Historical annual harvest data as far back in time as records are available. Units are cubic feet. If data are in other units, conversion factors are available in Stockman et al. (2014).
- Historical timber product data by softwood and hardwood classes (the proportion of total harvest that went into each timber product class [sawtimber, fuelwood, pulpwood, and other]). Regional averages are available if more local data are not.
- Historical end-use data by softwood and hardwood classes (the proportion of total harvest that went into end-uses [fuelwood, lumber, nonstructural panels, oriented strandboard (OSB), other industrial products, plywood, and wood pulp]). Regional averages are available if more local data are not.

These data may be used with one of several harvested wood product calculators. The Guidance Document provides more information on calculators and tools available.

Step 7. Estimate the total net greenhouse gas flux from forests over the inventory analysis period, and annualize the result into units of t CO_2e/yr

After the total net GHG flux from forests over the inventory period is calculated using Equation 2, the estimate is annualized into units of tCO_2e/year based on the number of years in the inventory analysis period using Equation 5.

$$Net\ GHG\ Flux = \frac{\left[\left(\frac{44}{12}\right) \times (\Delta C_{FRF} + \Delta C_{F \rightarrow NF} + \Delta C_{NF \rightarrow F} + \Delta C_{HWP})\right] + GHG_{nonCO2}}{T} \qquad \text{(Eq. 5)}$$

Where:

Net GHG Flux = net GHG flux from forests over inventory analysis period T (tCO_2e/year) (reflects the net balance of emissions and removals)

ΔC_{FRF} = change in carbon stocks in Forest Land Remaining Forest Land over the inventory period (t carbon; see Step 4.1)

$\Delta C_{F \rightarrow NF}$ = change in carbon stocks in Forest Land Converted to Non-Forest Land over the inventory period (tC; see Step 4.2)

$\Delta C_{NF \rightarrow F}$ = change in carbon stocks in Non-Forest Land Converted to Forest Land over the inventory period (tC; see Step 4.3)

ΔC_{HWP} = carbon additions to and losses from the stock of harvested wood products over the inventory period (tC; see Step 6)

GHG_{nonCO2} = CH_4 and N_2O emissions from biomass burning during prescribed fires or wildfires and soil N_2O emissions with mineral fertilization and organic amendments on Forest Land (tCO_2e; see Step 5)

T = total number of years of the inventory analysis period

44/12 = conversion factor to convert units of carbon to CO_2.

This estimate reflects the average annual net GHG flux over the inventory analysis period. It can be compared with estimates generated for previous periods (e.g., the reference period), as long as each estimate was developed using consistent methods, data, and approaches to ensure comparability.

Sample calculation 4. Estimating the total annual net greenhouse gas flux from forests

This example uses the figures from sample calculations 1, 2, and 3. It assumes that non-CO_2 gases and harvested wood products are not estimated.

Data:

ΔC_{FRF} = -1,258 tC

$\Delta C_{F \rightarrow NF}$ = 8,370 tC

$\Delta C_{NF \rightarrow F}$ = -860 tC

Calculation:

Change in carbon stock = [(44/12) x (-1,258 + 8,370 – 860)]/5 years = 4,584.8 tCO_2e/year

L.5 Trees outside Forest Land

This section covers "trees outside forest", or any trees or areas of tree cover that occupy land not defined as Forest Land in the IPCC land use matrix. The trees may fall within any of the yellow boxes in Table 10. For cities, the dark yellow box will likely be the focus, as most urban land area with tree cover will be classified as "Settlements Remaining Settlements."

Table 10. Land use and change matrix

	Forest	Cropland	Grassland	Wetlands	Settlements	Other
Forest	Forest Remaining Forest	Forest Converted to Cropland	Forest Converted to Grassland	Forest Converted to Wetlands	Forest co Converted to Settlements	Forest con Converted to Other Land
Cropland	Cropland Converted to Forest	Cropland Remaining Cropland	Cropland Converted to Grassland	Cropland Converted to Wetlands	Cropland Converted to Settlements	Cropland Converted to Other land
Grassland	Grassland Converted to Forest	Grassland Converted to Cropland	Grassland Remaining Grassland	Grassland Converted to Wetlands	Grassland Converted to Settlements	Grassland Converted to Other land
Wetlands	Wetlands Converted to Forest	Wetlands Converted to Cropland	Wetlands Converted to Grassland	Wetlands Remaining Wetlands	Wetlands Converted to Settlements	Wetlands Converted to Other land
Settlements	Settlements Converted to Forest	Settlements Converted to Cropland	Settlements Converted to Grassland	Settlements Converted to Wetlands	Settlements Remaining Settlements	Settlements Converted to Other land
Other Land	Other lands Converted to Forest	Other lands Converted to Cropland	Other lands Converted to Grassland	Other Lands Converted to Wetlands	Other lands Converted to Settlements	Other Lands Remaining Other Lands

Trees outside forests may be individual trees or trees in small patches embedded in a non-Forest Land category. Such trees may not be defined in substrata the same way as forest trees (e.g., by forest type). They may have a negligible effect on some carbon pools in the landscape, such as soil carbon. Unlike for forests (where the US Forest Service regularly monitors permanent sample plots and makes such data available), data sources for calculating emission and removal factors may be limited or lacking.

It is important to ensure that GHGs are not reported in more than one category. For example, if a community is reporting and accounting for Grassland, it should ensure that GHGs are not counted more than once when estimating GHGs for trees outside forests.

Both woody and herbaceous vegetation are present in land uses outside of forests, but for the purposes of this protocol, trees outside forests are considered the woody perennial vegetation in all non-Forest Land use classes (Croplands, Grasslands, Wetlands, Settlements, Other Lands). The simplification of including only the woody component of vegetation is made because the carbon stored in the woody components of trees makes up the largest compartment of standing biomass stocks and annual biomass increment in non-Forest Land uses. Guidance on the other carbon pools and emissions sources has not been developed in this version of the guidance

Recommended Approach: GHGs from trees outside forests are estimated using the following steps (which are identical to those developed for Forest Lands):

Step 1. Consider the need for further stratification

Trees outside forests occur in different landscapes within a community, which could affect the estimation of activity data and/or emissions and removal factors. Therefore, additional stratification may be desirable for the purposes of setting and monitoring specific policies (see Box 7). In addition to estimating GHG fluxes associated with changes in tree cover within the broad IPCC land use categories typically used for reporting (see Table 10), practitioners might consider creating additional strata to track GHG fluxes associated with, for example, distinct suburban areas or different community park and recreation areas within the Settlement class or different agroforestry systems within the Cropland or Grassland class.

It is more likely that communities collapse categories (combine yellow squares in Table 10 into a single stratum) than estimate GHGs for all 25 strata or create additional substrata, which would add to the complexity of the GHG estimation. Unlike for Forest Land, additional stratification of non-Forest Land is unlikely to significantly improve the accuracy or precision of emission/removal factors related to changes in biomass carbon.

Step 2. Estimate tree cover outside forests/urban canopy (activity data)

Sources of activity data for calculating the net GHG balance of trees outside forests are likely to be somewhat different than for forests. There are two ways to estimate activity data for trees/perennial vegetation outside of forests, depending on what data are available for a community to develop the estimates

(1) on the basis of the number of trees/perennial plants present in the inventory area;
(2) on the basis of tree crown or canopy cover

For areas classified as Settlements, the municipal agencies caring for urban vegetation may collect inventory data on individual trees (e.g., street trees) disaggregated into species or broad species classes, either on the ground through field data collection or remotely using very high-resolution aerial or satellite imagery. Tree lists are often developed by inventorying either all trees or a sample of trees in the community, with information collected for each measured tree typically including tree species, diameter at breast height (DBH), tree height, and information about tree health/mortality (if applicable).

For other non-Forest Land use classes outside of urban areas, or for areas where inventory data are not available for individual trees (as is likely in most communities), tree canopy cover data may be available from aerial photographs, three-dimensional light detection and ranging (LIDAR) imagery, or other satellite imagery. In these cases, the area of tree canopy outside of Forest Lands in the community can be estimated. If a community has this type of spatial data and is interested in knowing how the canopy is changing within a specific non-Forest class (or change class) *k*, tree canopy data can be disaggregated according to the yellow boxes of the matrix shown in Table 10. Otherwise, it is recommended that these trees be tracked as a single stratum, to simplify estimation and reporting.

To ensure that community lands are represented consistently in the inventory and to avoid double counting of trees, imagery used to delineate tree crown or canopy cover should be overlaid with the map used to delineate IPCC land use and change classes. After this overlay is performed, GHG fluxes associated with all categories of forest, including Forest Remaining Forest and conversions to and from Forest, should be addressed using the methods in Section L.4 for Forest Land. GHG fluxes associated with changes in tree canopy that occurred within each remaining non-Forest category *k* should be evaluated using Steps 3–7.

Step 3. Calculate emission and removal factors for trees outside forests

Methods for calculating carbon stocks and changes for trees are well developed for urban forestry in the United States; calculation tools are available to assist with the estimation process.[14] Usually, only the carbon in trees (including tree roots) is counted, as other carbon pools, such as soil carbon, are difficult to associate with individual trees within a non-Forest Land use category.

Two methods are described here. They can be applied to the two methods for estimating activity data described above.

The first method applies when activity data are available at the individual tree level through local inventories, where tree lists are developed by inventorying all trees (or a sample of trees) within each defined stratum. Models calibrated to the sampling area are then applied that convert data on tree species, DBH, tree height, dieback, crown light exposure, and distance and direction to buildings into estimates of storage, gross annual carbon sequestration, and net annual carbon sequestration (which accounts for tree mortality or death), including sampling errors.

The second method applies when activity data are available as estimates of the area of tree canopy outside forests. In this case, removal factors, or average rates of carbon sequestration per hectare of tree canopy per year, are estimated from inventories of urban forests from representative areas or by using regional averages. Such estimates can be found in look-up tables for different regions of the United States (see the Guidance Document). In the United States, data are available for urban tree canopies but not other classes of non-Forest Land with trees. If local data are not available for these other classes, it is recommended to use nearby urban tree cover data, as it is reasonable to assume that trees outside forests have biomass and growth characteristics that are similar to urban trees in similar geographic areas rather than trees in forests, which have much higher stocking density. If nearby urban tree data are not available, the best option is to use data from nearby forests.

Step 4. Calculate the carbon stock change from trees outside forests

Methods for calculating carbon stock changes associated with trees outside forests are slightly different from the simplified gain-loss method for forests. Changes in carbon stocks reflect the net balance of the sequestration that occurs where tree canopy is maintained and/or increased and the emissions that occur where tree canopy is lost.

$$\Delta C_{TOF} = \Delta C_{trees} + \Delta C_{treeloss} \qquad \text{(Eq. 6)}$$

$$\Delta C_{trees} = \sum_{k=1}^{K} AD_{trees\_k} \times RF_k \times T$$

$$\Delta C_{tree_{loss}} = \sum_{k=1}^{K} AD_{treeloss\_k} \times EF_k$$

where

[14] The guidance in this section is based on Hoover et al. (2014).

ΔC_{TOF} = net GHG flux from trees outside of forests over inventory analysis period T (reflects the net balance of emissions and removals) (tCO_2e)

AD_{trees_k} = average area of land with tree canopy cover over the inventory analysis period (hectares)

$AD_{treeloss\_k}$ = area of tree cover loss over the inventory analysis period (hectares)

RF_k = average removal factor (sequestration rate) of trees in non-forest category *k* (tC/hectare/year)

EF_k = average emission factor from loss of trees in non-forest category *k* (tC/hectare)

k = 1,2,3, …, K non-forest strata

T= number of years in the inventory period.

In some cases, activity data may be available only for one point in time, so that changes in tree canopy cannot be calculated. In these cases, only ΔC_{trees} can be calculated for the current inventory analysis period based on the average tree canopy cover; emissions associated with losses of tree cover should be considered during the next inventory period once these data are available.

Sample calculation 5 shows how to estimate changes in carbon stocks for trees outside forests.

Sample calculation 5. Estimating the change in carbon stocks for trees outside forests

This example is for an area in a hypothetical county that wants to track two strata over a five-year period—trees in settlement (urban trees) and trees on all other lands, and is using method (2) where activity data is based on area of tree canopy at two points in time, and emission and removal factors are based on GHG per ha (per year, for removals).

Simplified method:

Data:	Stratum 1: Tree canopy, area = 50 ha; tree loss, area = 1 ha
	Stratum 2: Tree canopy, area = 200 ha; tree gain, area = 10 ha
	Stratum 1 and 2: Removal factor (standing trees) = -3.0 tC per ha per year
	Stratum 1: Emission factor (tree loss) = 100 tC per ha
Calculations:	Stratum 1 gain = (-3.0 x 50) x 5 years = -750 tC
	Stratum 1 loss = (100 x 1) = 100 tC
	Stratum 2 gain = (-3.0 x 210) x 5 years = -3,150 tC
	C stock change = -750 + 100 – 3,150 = -3,800 tC (over 5-year period)

Step 5. Calculate non-CO_2 emissions, if appropriate

The main sources of non-CO_2 emissions from non-Forest Lands include (a) CH_4 and N_2O from biomass burning during prescribed fires or wildfires and (b) soil N_2O emissions with mineral fertilization and organic amendments. Other emissions may also occur, such as CH_4 from rice cultivation; guidance is not provided here because they are typically minor sources in most communities.

Step 5a. Estimate non-CO_2 emissions from biomass burning using Equation A.11 in the annex

The area of non-Forest Land that is burned may be available from remote sensing products or local mapping of fire extents. The biomass stock for the area could be based on data compiled to estimate biomass carbon stocks for disturbances for trees outside of forests (see Step 3). Biomass stocks for cropland residue burning may be derived using local data and methods in the US National Greenhouse Gas Inventory (US EPA 2017); Grasslands could be based on defaults provided in the 2006 IPCC guidelines (IPCC 2006). The emission factors, EF_{CH4} and EF_{N2O}, may be based on the values in the 2006 IPCC guidelines. The values are 4.7 ± 1.9 kg CH_4 per metric ton of biomass burned and 0.26 ± 0.07 kg N_2O per metric ton of biomass burned for temperate Forest Lands.

Step 5b. Estimate direct and indirect soil N_2O emissions using equations A.13–A.17 in the annex

Synthetic fertilizer application data may be available from sales data in the community or compiled from survey data. Application of organic amendments may be more challenging to compile, particularly if there is large amount of manure amendments from livestock farms in the area. IPCC (2006) provides methods for estimating manure production that could be used to approximate the amount of manure N available for application to soils. These methods require data on the livestock population in the county and the manure management systems.

The N content of fertilizers is available from fertilizer handbooks or manufacturing data. The N content pf manure depends on the livestock type. Values are provided in the *Agricultural Waste Management Field Handbook* (USDA 1996).

Emission factors may be based on values provided in the 2006 IPCC guidelines. They can also be based on state-level estimates of implied emission factors from the US National Greenhouse Gas Inventory (US EPA 2017).

Step 6. Calculate carbon stock changes in the harvested wood product pool, if appropriate

Urban and suburban areas are sources of wood for various uses, including fuelwood and mulch, often associated with tree maintenance. Roundwood products may also be provided from harvested trees outside forests. Therefore, it is likely to be important to keep track of the carbon sequestered or emitted in harvested wood products.

Methods to estimate carbon in harvested wood products and landfills from trees outside forests are nearly identical to methods described for forests in step 6 of section L.4. One significant difference, particularly for urban trees, is that some of the harvested wood will be in the form of yard waste and trimmings from tree maintenance. Some of this material may be mulched or directly deposited in landfills or dumps rather than disposed of following one of the lengthier pathways typical of harvests from forests. For assessing harvests of trees outside forests, different sources of data for estimating retention times for the stored carbon will be needed. Yard waste and trimmings not used for roundwood products would enter the calculations in the boxes labelled landfills, dumps, or compost in Figure 1, as appropriate.

Step 7. Estimate the total net greenhouse gas flux from trees outside forests over the inventory analysis period and annualize the result into units of tCO_2e

After the total net GHG flux from trees over the inventory period is calculated, the estimate is annualized into units of tCO_2e/year based on the number of years in the inventory analysis period.

$$Net\ GHG\ Flux = \frac{\left[\left(\frac{44}{12}\right)\times(\Delta C_{trees}+\Delta C_{treeloss})\right]+GHG_{nonCO2}}{T} \quad \text{(Eq. 7)}$$

where

Net GHG flux = net GHG flux from trees outside forests over inventory analysis period T (tCO_2e/year) (reflects the net balance of emissions and removals)

T = total number of years of the inventory analysis period

44/12 = conversion factor to convert units of carbon to CO_2.

This estimate reflects the average net GHG flux over the inventory analysis period. It can be compared with estimates generated for previous periods (e.g., the baseline), as long as each estimate was developed using consistent methods, data, and approaches to ensure comparability.

Annex: IPCC Gain-Loss Method for Estimating Greenhouse Gases from Forests

The IPCC gain-loss method is based on estimating the gains in carbon based on the age of forests in a community and the losses from harvest, fuelwood gathering, and stand-replacing disturbances. A community may decide to use this method if there are sufficient data on these activities and the age distribution of its forests.

The overall net GHG emissions or removals for all land uses is expressed as the sum of fluxes occurring within the six IPCC land use classes (Settlements, Forest Lands, Croplands, Grasslands, Wetlands, Other Lands). In this annex, the equations focus only on the gains and losses associated with Forest Lands and conversions to and from Forest Lands.

For each Forest Land use category *i* (Forest Land Remaining Forest Land, Land Converted to Forest Land, and Forest Land Converted to other land uses), net GHG emissions or removals are estimated as follows:

$$GHG_i = \Delta CS_i + NonCO2_i \qquad \text{(Eq. A.1)}$$

where

GHG_i = total greenhouse gas emissions for land use *i* (tCO_2e)

ΔCS_i = net carbon stock change in pools for land use *i* (tCO_2e)

$NonCO2_i$ = non-CO_2 greenhouse gas emissions for land use *i* (CH_4 or N_2O, in tCO_2e)

i = Settlements, Forest Lands, Croplands, Grasslands, Wetland, and Other Lands.

Carbon Stock Change

The change in carbon stocks for each land use is estimated as follows:

$$\Delta CS_i = \Delta BC_i + \Delta DOM_i + \Delta SOC_i + \Delta HWP_i \qquad \text{(Eq. A.2)}$$

where

ΔBC_i = change in biomass carbon stocks for land use *i* (tCO_2e)

ΔDOM_i = change in dead organic matter carbon stocks for land use *i* (tCO_2e)

ΔSOC_i = change in soil organic carbon stocks for land use *i* (tCO_2e)

ΔHWP_i = change in carbon stocks in harvested wood products for land use *i* (tCO_2e).

For Forest Land Remaining Forest Land and Land Converted to Forest Land, the change in biomass carbon stocks for each land use is estimated using the gain-loss method:

$$\Delta BC_i = (CG_i * A_i) - (CL_H + CL_F + CL_D) * 44/12 \qquad \text{(Eq. A.3)}$$

where

CG_i = increase in biomass carbon stocks for land use *i* (metric tons carbon per hectare)

A_i = area for corresponding increase in biomass carbon stock for land use *i* (hectare)

CL_H = carbon losses from harvest of wood for land use *i* (tC)

CL_F = carbon losses from fuelwood gathering for land use *i* (tC)

CL_D = carbon losses from disturbance for land use *i* (tC)

44/12 is the conversion from carbon to CO_2.

The carbon gain in biomass ($\mathrm{CG_i}$) is estimated as follows:

$$CG_i = AGI_i \ * (1 + R_i) * CF \quad \text{(Eq. A.4)}$$

where

AGI_i = growth increment in aboveground biomass (tC per hectare)

R_i = ratio of belowground biomass to aboveground biomass

CF = carbon fraction of biomass (tC per metric ton of biomass)

The carbon loss from harvest (CL_H) is estimated as follows:

$$CL_H = H_t * D_t * BEF_t * (1 + R_i) * CF \quad \text{(Eq. A.5)}$$

where

H_t = volume of harvest for tree type *t* associated with land use *i* (cubic meters)

D_t = density of the wood for tree type *t* (dry weight metric tons of biomass per cubic meter)

BEF_t = biomass expansion factor from the harvested portion of the tree to the entire tree, including branches and leaves for tree type *t* associated with land use *i* (cubic meters)

R_i = ratio of belowground biomass to aboveground biomass

CF = carbon fraction of the biomass (tC per metric ton of biomass).

The carbon loss from fuelwood gathering (CL_F) is estimated as follows:

$$CL_F = \{[W_t * D_t * BEF_t * (1 + R_i)] + [P_t * D_t]\} * CF \quad \text{(Eq. A.6)}$$

where

FG_t = volume of whole tree harvesting for fuelwood by tree type *t* associated with land use *i* (cubic meters)

D_t = density of the wood for tree type *t* (dry weight metric tons of biomass per cubic meters)

BEF_t = biomass expansion factor from the harvested portion of the tree to the entire tree including branches and leaves for tree type *t* associated with land use *i* (cubic meters)

R_i = ratio of belowground biomass to aboveground biomass

P_t = volume of partial tree harvesting for fuelwood by tree type *t* associated with land use *i* in which the entire tree is not killed (cubic meters)

CF = carbon fraction of the biomass (tC per metric ton of biomass).

The carbon loss from disturbances (CL_D), such as fires, diseases, pest outbreaks, hurricanes, other events that destroy a majority of the trees, is estimated as follows:

$$CL_D = S_i * (1 + R_i) * CF * FL_i * A_i \quad \text{(Eq. A.7)}$$

where

S_i = standing stock of biomass in the area of the disturbance for land use *i* (metric tons per hectare)

R_i = ratio of belowground biomass to aboveground biomass for land use *i*

CF = carbon fraction of the biomass (tC per metric ton of biomass)

FL_i = fraction of biomass lost due to the disturbance for land use *i*

A_i = area affected by disturbances for land use *i* (hectares).

The change in biomass carbon stocks for each land use is estimated using the production approach. For Forest Land Converted to Other Land uses (deforestation), the change in biomass carbon stocks for each land use (ΔBC_i) is estimated as follows:

$$\Delta BC_i = [\Delta Ccon_i + (CG_i * A_i) - (CL_H + CL_F + CL_D)] * 44/12 \quad \text{(Eq. A.8)}$$

where

$\Delta Ccon_i$ = initial change in carbon for land use conversion *i* (tC)

CG_i = increase in biomass carbon stocks for land use conversion *i* (tC per hectare)

A_i = area for corresponding increase in biomass carbon stock for land use conversion *I* (hectares)

CL_H = carbon losses from harvest of wood for land use conversion *i* (tC)

CL_F = carbon losses from fuelwood gathering for land use conversion *i* (tC)

CL_D = carbon losses from disturbance for land use conversion *i* (tC)

44/12 is the conversion from carbon to CO_2.

The initial change in carbon during the year of conversion for land use conversion is estimated as follows:

$$\Delta Ccon_i = [(Bafter_i - Bbefore_i) * A_i] * CF \quad \text{(Eq. A.9)}$$

where

$Bafter_i$ = biomass stock after conversion for land use conversion *i* (tC)

$Bbefore_i$ = biomass stock before conversion for land use conversion *i* (tC)

A_i = area for conversion during the inventory year or an average area over the analysis time period for land use conversion *i* (hectares)

CG_i, CL_H, CL_F, and CL_D are estimated using equations 5, 6, 7, and 8, respectively.

Non-CO_2 Emissions

Non-CO_2 greenhouse gas emissions are estimated for the soil N_2O emissions associated with synthetic fertilization and organic amendments and the CH_4 and N_2O emissions from the burning of biomass in fires. Other sources of N also affect soil N_2O emissions; this guidance focuses on the two main practices, with the goal of providing methods that are more tractable for communities. Communities may refer to the 2006 IPCC guidelines for additional guidance if they decide to include additional practices.

The method associated with biomass burning has been simplified. Trace gases are released as biomass burns (referred to as *precursors*), which undergo other reactions in the atmosphere to form GHGs. The estimation of precursors is not included in this guidance. Precursors may be estimated using the 2006 IPCC guidelines.

Total non-CO_2 emissions are estimated as follows:

$$NonCO2_i = BB_i + NM_i \quad \text{(Eq. A.10)}$$

where

BB_i = total biomass burning emissions for land use *i* (tCO_2e)

NM_i = total soil nitrous oxide emissions from soil nitrogen management for land use *i* (tCO_2e).

Total emissions from biomass burning are estimated as follows.

$$BB_i = A_i * M_i * CB_i * [(EF_{CH4} * GWP_{CH4}) + (EF_{N2O} * GWP_{N2O})] * 10^{-3} \quad \text{(Eq. A.11)}$$

where

A_i = area affected by disturbances for land use *i* (hectares)

M_i= biomass stock in the area affected by the disturbance for land use *i* (metric tons dry matter per hectare)

CB_i = proportion of biomass oxidized in the area affected by the disturbance for land use *i*

EF_{CH4} = emission factor for CH_4 (kg CH_4 emitted per metric ton dry matter burned)

GWP_{CH4} = global warming potential of CH_4 over 100-year time horizon (kg CO_2e per kg CH_4)

EF_{N2O} = emission factor for N_2O (kg N_2O emitted per metric ton dry matter burned)

GWP_{N2O} = global warming potential of N_2O over 100-year time horizon (kg CO_2e per kg N_2O)

The multiplier of 10^{-3} is the conversion from kg CO_2e to metric tons of CO_2e (tCO_2e).

Total emissions from soil nitrogen management are estimated for direct and indirect soil N_2O as follows:

$$NM_i = (DE_i + IE_i) * GWP_{N2O} \quad \text{(Eq. A.12)}$$

where

DE_i = direct soil N_2O emissions for land use *i* (metric tons N_2O)

IE_i = total indirect soil N_2O emissions for land use *i* (metric tons N_2O)

GWP_{N2O} = global warming potential of N_2O over 100-year time horizon (tCO_2e per metric ton N_2O).

Direct soil N_2O emissions (DE_i) are estimated as follows:

$$DE_i = [(SN_i * N_{SN} * EF_{SN}) + (OA_i * N_{OA} * EF_{OA})] * 44/28 \quad \text{(Eq. A.13)}$$

where

EF_{SN} = N_2O emission factor for synthetic fertilizer applied to soils (kg N_2O-N per kg N applied)

OA_i = amount of organic amendments applied to soils for land use *i* (kg dry matter applied)

N_{OA} = proportion of N in organic amendments (kg N per kg dry matter applied)

EF_{OA} = N_2O emission factor for organic amendments applied to soils (kg N_2O-N per kg N applied)

44/28 is the conversion from N_2O-N to N_2O.

Total indirect soil N_2O emissions are estimated for volatilized losses of N (NO_x and NH_3) at the site of application plus the losses of N through water flows, leaching, and runoff (NO_3 and organic forms of N), at the site of application as follows:

$$IE_i = IEV_i + IEW_i \quad \text{(Eq. A.14)}$$

where

IEV_i = indirect soil N_2O emissions from volatilization of N at the site of application for land use *i* (metric tons N_2O)

IEW_i = indirect soil N_2O emissions with N losses in water flows (leaching and runoff) at the site of application for land use *i* (metric tons N_2O).

Indirect soil N_2O emissions from volatilized losses of N are estimated as follows:

$$IEV_i = [(SN_i * N_{SN} * FV_{SN} * EFV_{SN}) + (OA_i * N_{OA} * FV_{OA} * EFV_{OA})] * 44/28 \quad \text{(Eq. A.15)}$$

where

SN_i = amount of synthetic fertilizer applied to soils for land use *i* (kg fertilizer applied)

N_{SN} = proportion of N in synthetic fertilizer (kg N per kg synthetic fertilizer)

FV_{SN} = fraction of synthetic N applied to soils that is volatilized from the site of application

EFV_{SN} = indirect N_2O emission factor for synthetic fertilizer N applied to soils that is lost through volatilization from the site of application (kg N_2O-N per kg N applied)

OA_i = amount of organic amendments applied to soils for land use *i* (kg dry matter applied)

N_{OA} = proportion of N in organic amendments (kg N per kg dry matter applied)

FV_{OA} = fraction of N in organic amendments applied to soils that is volatilized from the site of application

EFV_{OA} = indirect N_2O emission factor for N in organic amendments applied to soils that is lost through volatilization from the site of application (kg N_2O-N per kg N applied)

44/28 is the conversion from N_2O-N to N_2O.

Indirect soil N_2O emissions from losses of N in water flows (leaching and runoff) are estimated as follows:

$$IEW_i = [(SN_i * N_{SN} * FW_{SN} * EFW_{SN}) + (OA_i * N_{OA} * FV_{OA} * EFW_{OA})] * 44/28 \quad \text{(Eq. A.16)}$$

where

SN_i = amount of synthetic fertilizer applied to soils for land use *i* (kg fertilizer applied)

N_{SN} = proportion of N in synthetic fertilizer (kg N per kg synthetic fertilizer)

FV_{SN} = fraction of synthetic N applied to soils that is lost in water flows (runoff and leaching) from site of application

EFW_{SN} = indirect N_2O emission factor for synthetic fertilizer N applied to soils that is lost in water flows (runoff and leaching) from the site of application (kg N_2O-N per kg N applied)

OA_i = amount of organic amendments applied to soils for land use *i* (kg dry matter applied)

N_{OA} = proportion of N in organic amendments (kg N per kg dry matter applied)

FV_{OA} = fraction of N in organic amendments applied to soils that is volatilized from the site of application

EFW_{OA} = N_2O emission factor for N in organic amendments applied to soils that is lost in water flows (runoff and leaching) from the site of application (kg N_2O-N per kg N applied)

44/28 is the conversion from N_2O-N to N_2O.

References

Bell, R. and Wheeler, J. 2006. Talking Trees An Urban Forestry Toolkit for Local Governments. Published by ICLEI Local Governments for Sustainability.

Birdsey, Richard; Dugan, Alexa; Healey, Sean; Dante-Wood, Karen; Zhang, Fangmin; Chen, Jing. 2019. Assessment of the influence of disturbance, management activities, and environmental factors on carbon stocks of United States National Forests. Fort Collins, Colorado: Gen. Tech. Report RM-xxx. Xxx pages plus online appendices. IN PRESS.

Henders, S., U.M. Persson, and T. Kastner. 2015. "Trading Forests: Land Use Change and Carbon Emissions Embodied In Production and Exports of Forest-Risk Commodities." *Environmental Research Letters* 10 (12): 125012.

Hoover, C., R. Birdsey, B. Goines, P. Lahm, Gregg Marland, D. Nowak, S. Prisley, E. Reinhardt, K. Skog, D. Skole, J. Smith, C. Trettin, C. Woodall, 2014. Chapter 6: Quantifying Greenhouse Gas Sources and Sinks in Managed Forest Systems. In Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. Technical Bulletin Number 1939, Office of the Chief Economist, US Department of Agriculture, Washington, DC. 606 pages. July 2014. Eve, M., D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, and S. Biggar, Eds.

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Edited by H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara and K. Tanabe. Japan: IGES. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Iversen P., D. Lee and M. Rochectares. 2014. *Understanding Land Use in the UNFCCC*. http://www.climateandlandusealliance.org/reports/understanding-land use-in-the-unfccc/.

Nowak, D.J., E.J. Greenfield, R. Hoehn, and E. LaPoint. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution, 178:229-236.

Ogle, S.M., P. Hunt, C. Trettin, 2014. Chapter 4: Quantifying Greenhouse Gas Sources and Sinks in Managed Wetland Systems. In *Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory*. Technical Bulletin Number 1939, Office of the Chief Economist, US Department of Agriculture, Washington, DC. 606 pages. July. Eve, M., D. Pape, M. Flugge, R. Steele, D. Man, M. Riley-Gilbert, and S. Biggar, Eds.

Olofsson, P. et al. Good practices for estimating area and assessing accuracy of land change. Remote Sensing of Environment 148 (2014) 42-57.

Pearson, T.R.H., S.L. Brown, and R.A. Birdsey. 2007. Measurement guidelines for the sequestration of forest carbon. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station.

Raymond CL, Healey S, Peduzzi A, Patterson P (2015) Representative regional models of post-disturbance forest carbon accumulation: Integrating inventory data and a growth and yield model. Forest Ecology and Management 336: 21-34.

Smith, J.E., L.S. Heath, K.E. Skog, and R.A. Birdsey. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station.

Stockmann, K., Anderson, N., Young, J., Skog, K., Healey, S., Loeffler, D., Butler, E., Jones, J. G. & Morrison, J. 2014. Estimates of carbon stored in harvested wood products from United States Forest Service

Northern Region, 1906-2012. Missoula, MT: US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory. 27 p.

USDA. 1996. Agricultural Waste Management Field Handbook, National Engineering Handbook (NEH), Part 651. Natural Resources Conservation Service, US Department of Agriculture. July 1996.

US EPA. 2019. Inventory of US Greenhouse Gas Emissions and Sinks: 1990-201, Chapter 6. Land Use, Land-use Change, and Forestry, US-Environmental Protection Agency, Washington, D.C.