GREENHOUSE GAS PROTOCOL

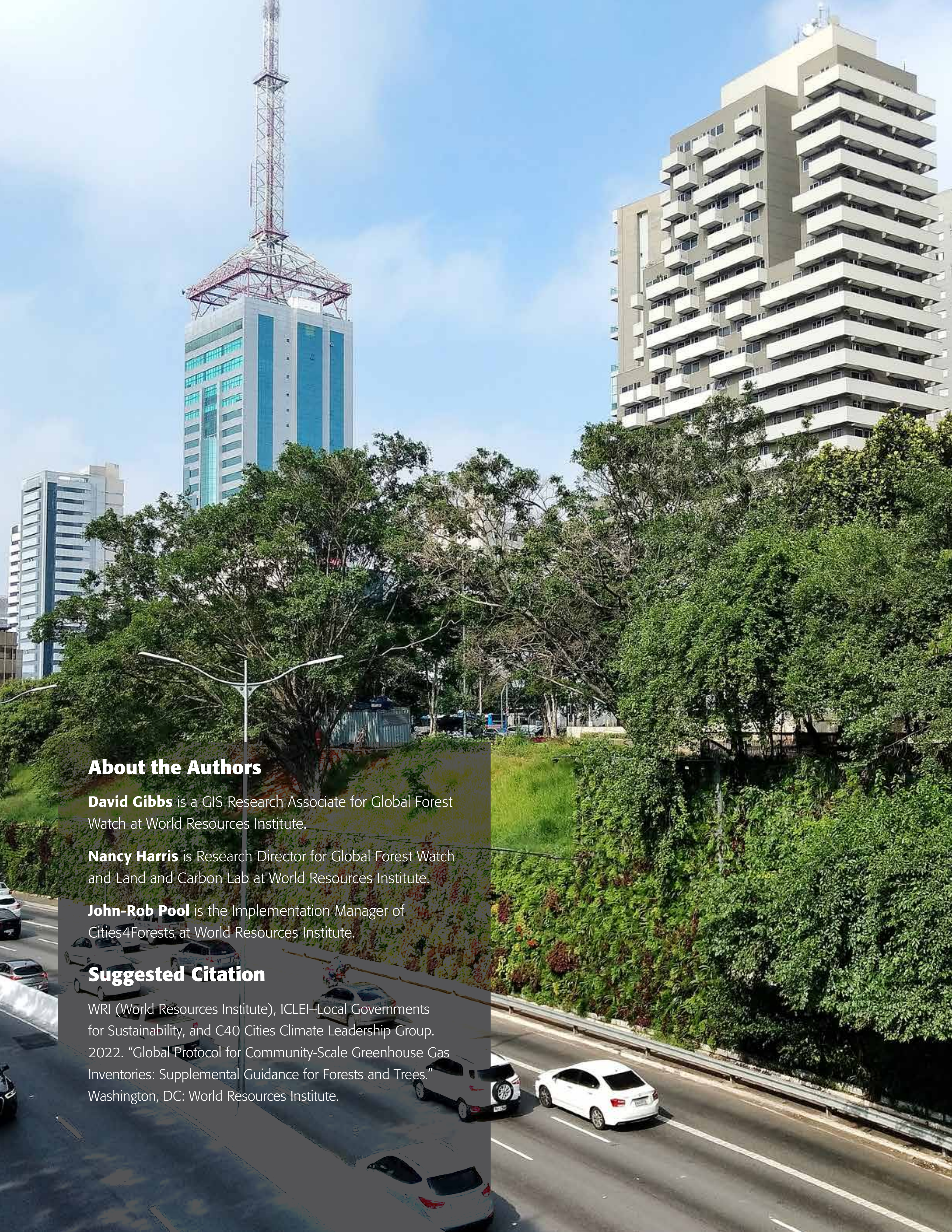
Global Protocol for Community-Scale Greenhouse Gas Inventories

Supplemental Guidance for Forests and Trees

WORLD RESOURCES INSTITUTE

C40 CITIES

ICLEI Local Governments for Sustainability



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Executive Summary

Greenhouse gas (GHG) emissions are driving climate change and its impacts around the world. Drastic and sustained emission reductions are needed across all sectors and by all actors to mitigate these impacts. At the same time, recent Intergovernmental Panel on Climate Change (IPCC) reports state that all mitigation pathways compatible with limiting global warming to 1.5 degrees Celsius (°C) by 2100 also involve significant removal of carbon dioxide (CO_2) from the atmosphere, highlighting the importance of both maintaining and expanding the ability of forests and trees outside forests (collectively called forests and trees) to capture and store carbon. Actions taken by local communities will be key to meeting the climate action targets set by national and international agreements. As communities ramp up forest- and tree-based mitigation, they must also measure what forests and trees are already doing.

Despite international enthusiasm for nature-based climate solutions,[1] many local GHG inventories and climate action plans do not include forests and trees outside forests (collectively called forests and trees). This *Supplemental Guidance for Forests and Trees* elaborates on the updated Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (hereafter referred to as the GPC) (WRI et al. 2021) and provides GHG inventory compilers with globally standardized, yet flexible, guidance for estimating GHG emissions and CO_2 removals (collectively called GHG fluxes) associated specifically with forests and trees within the boundaries of cities, towns, counties, or other subnational jurisdictions (collectively called communities). Where possible, it uses simplified methods designed to fit communities' circumstances and decision-making needs while preserving the ability to produce GHG inventories that support transparent and ambitious community-scale climate policies.

This supplement is designed to be used in conjunction with the GPC (WRI et al. 2021), and it expands upon the GPC's guidance for the "Land" sub-sector of the Agriculture, Forestry, and Other Land Uses (AFOLU) sector by providing detailed methods for estimating emissions from and removals by forests and trees within a community's GHG accounting boundary (Scope 1). Specifically, it expands on the GPC's Section 10.4 ("Calculating Land Use and Land-Use Change Emissions"). It also broadens the U.S. Community Protocol's "Appendix J: Forest Land and Trees" (ICLEI 2019) to be applicable to communities around the world. As in the GPC and U.S. Community Protocol, the GHG inventory methods presented here are informed by, and broadly consistent with, the 2019 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2019b). During its development, this supplement was tested with communities around the world.

1. Nature-based solutions (NBS) are activities that harness the power of nature to reduce the accumulation of GHGs in the atmosphere and provide benefits for adaptation, biodiversity, and human well-being. The terms *nature-based solutions* and *natural climate solutions* (NCS) are often used interchangeably, but whereas NBS tend to refer to a broad suite of activities contributing to climate adaptation as well as mitigation, NCS are often focused more narrowly on reduction or removal of carbon emissions (Seddon et al. 2020).

This supplement is divided into four parts:

- Part I outlines the scope and coverage of the supplement (Chapter 1), introduces key concepts related to land-related GHG fluxes (Chapter 2), and provides an overview of methods used to conduct GHG inventories of forests and trees (Chapter 3).
- Part II outlines how communities shall delineate and represent their land in the inventory (Chapter 4), offers considerations for how frequently GHG fluxes from land can and shall be updated and reported (Chapter 5), and summarizes the data needed (Chapter 6) to implement the calculation guidance.
- Part III provides calculation methods and equations for estimating GHG emissions and CO_2 removals by forests (Chapter 7) and trees outside forests (Chapter 8) occurring within a community's inventory boundary.
- Part IV shows how GHG fluxes associated with forests and trees shall be reported within the GPC's inventory reporting framework (Chapter 9), and how the inventory results can be used to set and/or revise mitigation goals (Chapter 10).

All requirements ("shall" statements) for conducting a forest and tree GHG inventory are included in Appendix A.

Part I: Background and methods overview

Forests and trees store carbon in multiple pools, or reservoirs, such as biomass and soil. The transfer of carbon from terrestrial pools to the atmosphere results in carbon dioxide (CO_2) emissions, while the reverse—transfer of carbon from the atmosphere to terrestrial pools—results in CO_2 removals, or sequestration. Forests and trees both emit CO_2 into and remove CO_2 from the atmosphere, and they can also emit other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O). The balance between CO_2 emissions (plus non-CO_2 greenhouse gas emissions) and removals in a specific area over a specific time is the net GHG flux.

Just like countries, communities can use forests and trees to help achieve their climate change mitigation goals. Although the GPC does not require the Agriculture, Forestry, and Other Land Uses sector to be included in the GPC's BASIC reporting level, inclusion of this sector is required for the BASIC+ reporting level and for communities in which this sector is significant. While the GPC's Section 10.4 provides guidance on conducting a GHG inventory for the "Land" sub-sector, it does not address the complexity of estimating emissions from and removals by land. The dual role of forests and trees as GHG sources (emissions exceed removals) and sinks (removals exceed emissions), along with their variability over time in response to both human and natural processes, poses unique monitoring challenges for communities that wish to include them in their GHG inventory.

This supplement has the following objectives:

- Publish methods that enable communities to cost-effectively include forests and trees in their local GHG inventories in a way that helps community leaders and their constituents plan their climate change mitigation actions.
- Create international consistency and transparency in the way communities develop GHG inventories for forests and trees, while recognizing each community's unique circumstances and needs.
- Support the reconciliation of national GHG inventories and subnational monitoring to inform mitigation targets (for example, nationally determined contributions) under the UN Framework Convention on Climate Change (UNFCCC).
- Help cities and other subnational actors understand how forests and trees can contribute to ambitious and transparent climate change mitigation goals.

GHG emissions and removals related to the "Land" sub-sector are calculated within six main land uses—*Forest Land, Cropland, Grassland, Settlements, Wetlands,* and *Other Land*[2]—all of which can include both GHG emissions and CO_2 removals. This supplement presents methods for estimating emissions and removals separately by combining activity data with emission factors (in the case of emissions) or carbon gain factors (in the case of removals) for the following categories:

2. For clarity, IPCC land-use categories are capitalized and written in italics. Names of sectors are capitalized and set in regular roman type, while sub-sectors are written the same way but enclosed in quotation marks.

- *Forest Land*: This supplement covers GHG emissions resulting from *Forest Land converted to Non-Forest Land* (deforestation) and emissions occurring on *Forest Land remaining Forest Land* resulting from disturbances, such as fires and timber harvesting. It covers removals associated with *Non-Forest Land converted to Forest Land* (afforestation or reforestation) and removals occurring on undisturbed *Forest Land remaining Forest Land*.
- *Non-Forest Land* (*Cropland, Grassland, Settlements, Wetlands, Other Land*): This supplement covers GHG emissions and removals associated with trees on *Non-Forest Land* (i.e., trees outside forests), including urban trees. This is a step toward comprehensive inventory coverage of *Non-Forest Land* GHG fluxes, which would also include guidance for calculating GHG fluxes associated with managed agricultural and wetland soils.

This supplement does not provide guidance on calculating GHG fluxes associated with managed agricultural and wetland soils, indirect emissions due to consumption of products associated with deforestation occurring outside the community boundary (Scope 3 emissions, which will be covered in future GPC guidance), or the indirect benefits or land-use trade-offs associated with local changes in forest and tree cover (Table ES-1).

Table ES-1 Coverage of this supplement

Topic		The Supplement Covers:	The Supplement Does Not Cover:
GHG component	*Forest Land*	Emissions (biomass and soil) and removals (biomass only) by *Forest Land*, including land-use changes and forest disturbances.	Changes in carbon stored in harvested wood products or substitution effects for harvested wood products, changes in deadwood or litter pools in *Forest Land*.
	Non-Forest Land	Emissions from and removals by trees on *Non-Forest Land* (biomass only).	Nontree aspects of *Non-Forest Land* (e.g., soil carbon changes on agricultural lands or wetlands).
	Soil	Emissions from soil during land-use changes involving *Forest Land* (deforestation).	Carbon sequestered by *Forest Land* soils, and all aspects of managed soils on *Non-Forest Land* (e.g., *Cropland, Grassland, Wetlands*).
	Biomass or residue burning	CO_2 and non-CO_2 emissions from forest fires.	Biomass burning for energy (reported in Stationary Energy sector; GPC, Chapter 6).
	Biomass in landfill	N/A	Any aspect (reported in Waste sector; GPC, Chapter 8).
Scopes		Scope 1 emissions and removals (territorial GHG fluxes).	Scope 3 emissions (e.g., GHG emissions associated with displacement of land development to nearby municipalities due to maintenance or growth of urban tree cover in the inventoried community), indirect impacts beyond Scope 3 (e.g., GHG consequences of land-use change caused by consumption of products within the community).

Table ES-1 Coverage of this supplement, continued

Topic	The Supplement Covers:	The Supplement Does Not Cover:
Approach	Historical GHG emission or removal inventory.	Product GHG life-cycle assessments (e.g., for harvested wood products).
Resources	A framework for communities to understand the magnitude and direction of GHGs from forests and trees. (A link to a sample worked inventory spreadsheet is provided in Appendix D.)	Specific data sources, tools, or inventory calculators.
Policy relevance	Information that can be used to inform and track climate-friendly policies. Guidance on integrating forest and tree GHGs into the broader GHG inventory and climate action targets.	Estimates that can be used for selling carbon credits (see Box 6). Methods to measure the indirect or non-GHG impacts of forests and trees.
Output	The development of a local GHG inventory consistent with IPCC national inventory methods.	Estimation of the GHG impacts of specific mitigation activities, or projection of GHG fluxes.

Notes: GHG = greenhouse gas; GPC = Global Protocol for Community-Scale Greenhouse Gas Emission Inventories; IPCC = Intergovernmental Panel on Climate Change.

Part II: Setting up the inventory

Communities must make several decisions before they can perform emissions or removals calculations for forests or trees. These decisions are generally interdependent and iterative. The process for calculating GHG fluxes for forests and trees is similar. Communities that include the "Land" sub-sector shall include GHG fluxes for all forest-related land-use transitions (i.e., deforestation and afforestation or reforestation), *Forest Land remaining Forest Land*, and trees on *Non-Forest Land.*

1. Communities must decide what area to include in the inventory and how to represent the land within it. Once a community's land base has been delineated, it shall be classified into six land-use categories: *Forest Land, Cropland, Grassland, Wetlands, Settlements, and Other Land* (IPCC 2019b). The six IPCC land-use categories may be disaggregated into additional subcategories to improve calculations or to increase detail in reporting; for example, *Forest Land* can be split among different ownership or forest type subcategories. The chosen land-use classification shall exhaustively and exclusively cover the inventory land area. However, land use at one time does not allow estimation of GHG fluxes; land-use change must be estimated and is represented as a land-use change matrix (Table ES-2). The land-use change matrix is the basis of the activity data needed for forest GHG flux calculations. The *Forest Land* delineation and classification, including land-use transitions between *Forest Land* and *Non-Forest Land*, is used for the *Forest Land* part of the inventory. The *Non-Forest Land* delineation and classification is used for the "trees outside forests" part of the GHG inventory.
2. Communities must decide on an inventory update cycle. The forest and tree GHG inventory must span enough time to assess change (i.e., multiple years). In practice, the inventory cycle is determined largely by the availability of activity data (land-use and tree-canopy data). Although the relevant activity data may span multiple years, the inventory shall be reported for a continuous 12-month period, as required by the GPC.
3. Activity data and emission and carbon gain factors must be selected.

Table ES-2 **6x6 category land-use change matrix**

Land use at start of inventory cycle	Land use at end of inventory cycle: *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*

Note: Each cell represents the area of land that started in a given land-use category and ended in a given land-use category over an inventory cycle.

- *Forest Land remaining Forest Land*
- *Non-Forest Land converted to Forest Land*
- *Forest Land converted to Non-Forest Land*
- *Non-Forest Land remaining Non-Forest Land* on which changes to trees on *Non-Forest Land* are tracked
- Land use stayed the same use during the inventory

- **Activity data** are a quantitative measure of a level of activity that results in GHG emissions. In the context of forests and trees, these data include land-use change, *Forest Land* disturbances, and loss, gain, and maintenance of trees on *Non-Forest Land*.
- In the context of forests and trees, **emission factors** are the CO_2 emitted from each carbon pool per unit of land area.
- **Carbon gain factors** are the carbon accumulated by vegetation per unit area of land use during a specified time, usually one year.

Identifying sources of data to estimate activity data and emission and carbon gain factors may be the most complicated part of the GHG inventory. Table ES-3 shows the data needed for a forest and tree GHG inventory. Some communities may have only one source of data for a given row, while others may have multiple data sources from which to choose. Potential data sources include community maps or tree censuses, national land-use maps or GHG inventories, or IPCC default values. This supplement provides general guidance on where to find data and how to decide which data to use, but this process is ultimately context-dependent, and communities should determine what best suits their needs given the information, time, and resources available.

Table ES-3 **Summary of data sources needed for compiling a GHG inventory for forests and trees**

	Row	Data Category	Sub-category	Type of Data Needed (Units)	Supplement Section
Forest Land	1	Activity data	Land-cover change / land-use change	Land-cover or land-use maps for multiple years (to derive land-use change matrix) (ha)	6.1
	2	Activity data	Forest disturbances	Area (and location and intensity) of *Forest Land* burned (ha)	
	3	Activity data	Forest disturbances	Area (and location and intensity) of *Forest Land* harvested (ha)	
	4	Activity data	Forest disturbances	Area (and location and intensity) of other dis-turbances (pest, wind, etc.) in *Forest Land* (ha)	
	5	Activity data	Forest disturbances	Annual timber harvest, fuelwood statistics (m^3 for timber or fuelwood; t for fuelwood)	
	6	Activity data	Forest subcategories	Area (and location) of different forest types, ownership classes, etc. (ha)	
	7	Emission factors	Forest emission factors	Forest carbon density in different forest types and pools (aboveground biomass, belowground biomass, deadwood, litter, soil organic carbon) (t C/ha)	6.2
	8	Carbon gain factors	Forest carbon gain factors	Mean annual increment or biomass carbon accumulation rate in different forest types and/ or age classes (t C/ha/yr)	
Non-Forest Land	9	Activity data	Trees on *Non-Forest Land*	Area of tree canopy or tree census for multiple years (ha of tree canopy or # of trees)	6.3
	10	Activity data	Trees on *Non-Forest Land* subcategories	Area (and location) of different *Non-Forest Land* subcategories (ha)	
	11	Emission factors	Trees on *Non-Forest Land* emission factors	Carbon density in trees on *Non-Forest Land* (t C/ha of tree canopy or per tree)	6.4
	12	Carbon gain factors	Trees on *Non-Forest Land* carbon gain factors	Biomass carbon accumulation per area of canopy cover or per tree by trees on *Non-Forest Land* (t C/ha/yr or t C/tree/yr)	

Note: Not all data types are needed for all communities. For example, not all communities have burned *Forest Land*.

Part III: Calculation guidance

Steps for conducting the forest and tree GHG inventory are shown in Figure ES-1.

These steps apply to both the *Forest Land* and trees on *Non-Forest Land* parts of the GHG inventory, which can generally be conducted in parallel. For both, the first step is to delineate the land area included in the inventory. Then, data sources must be selected (Stage 1), as described above. Next, communities calculate and assign activity data, emission factors, and carbon gain factors (Stage 2). After that, communities perform the following calculations for gross emissions and gross removals:

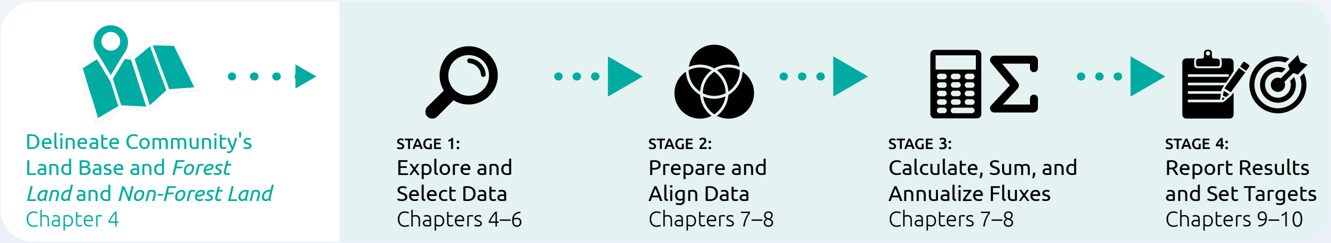
- Emissions from *Forest Land converted to Non-Forest Land*
- Emissions from disturbances on *Forest Land remaining Forest Land* (including non-CO_2 emissions)
- Emissions from loss of trees on *Non-Forest Land*
- Removals by *Non-Forest Land converted to Forest Land*
- Removals by *Forest Land remaining Forest Land* (undisturbed forest)
- Removals by trees gained and maintained on *Non-Forest Land*.

Equations and sample calculations are provided for each of the components above. Once those components have been calculated, they shall be combined into gross emissions, gross removals, and net GHG flux over the relevant inventory cycle and then annualized. Annual reporting of GHG fluxes from forests and trees, as required by the GPC, allows comparison of estimates across consecutive inventory cycles and with emissions from other sectors. A link to a sample worked inventory spreadsheet is provided in Appendix D.

Part IV: Reporting and setting goals

Following instructions on calculating GHG fluxes, this supplement provides guidance on how to report GHG fluxes from *Forest Land* and trees on *Non-Forest Land* as part of a multisector inventory and as stand-alone information. Reporting requirements for including "Land" sub-sector GHG fluxes are listed. Among other requirements, communities shall report emissions and removals separately for the "Land" sub-sector (rather than only as a single net GHG flux estimate) and report the inventory total as a gross estimate (emissions from all sectors) as well as a net estimate (emissions from all sectors, minus any "Land" sub-sector removals). This increases transparency in reporting and

Figure ES-1 Overview of steps for compiling a GHG inventory for forests and trees



Source: Authors.

serves as a reminder that the "Land" sub-sector has dual mitigation pathways of reducing emissions and increasing carbon removals by forests and trees.

The final chapter discusses how *Forest Land* and trees on *Non-Forest Land* can be integrated into communities' climate action plans and mitigation goals. While the goal of GHG inventories is to report as accurately and comprehensively as possible, climate mitigation targets (and the emissions, removals, and activities covered) can be set in different ways. Communities should clearly define the boundary of their target(s) and may set a variety of targets. When incorporating "Land" sub-sector removals into their targets, and when setting the level of the targets, communities should carefully consider their starting point of removals relative to emissions. For some communities, it will make more sense to have separate emissions and removals goals and/or separate "Land" sub-sector targets, while, for others, having one goal for emissions and removals combined may be more appropriate.

Using this supplement, communities can track GHG fluxes from forests and trees, integrate them into their GHG inventories, and include this sub-sector in community GHG target setting. Ultimately, this will increase community awareness of how forests and trees affect GHG fluxes and indicate additional opportunities for communities to pursue and track nature-based climate solutions.

PART I
Background and methods overview

Part I of this supplement introduces key concepts and provides an overview of the methods for conducting greenhouse gas (GHG) inventories of forests and trees outside forests. Chapter 1 explains the purpose of this supplement and what it covers. Chapter 2 summarizes how land interacts with the atmosphere via GHG pathways. Chapter 3 outlines how the inventory is conducted. Part I will be particularly helpful for communities that are including forests and trees in their inventories for the first time.

1 Introduction

Greenhouse gas emissions are driving climate change and its impacts around the world (IPCC 2021). Drastic and sustained emission reductions are needed across all sectors and by all actors to mitigate these impacts. At the same time, several recent reports by the Intergovernmental Panel on Climate Change (IPCC) state that all mitigation pathways compatible with limiting global warming to 1.5 degrees Celsius (°C) by 2100 also involve substantial removal (sequestration) of carbon dioxide (CO_2) from the atmosphere (henceforth, "removals") (IPCC 2019a, 2021). Forests and trees outside forests (collectively, "forests and trees") remove significant amounts of CO_2, highlighting the importance of maintaining and expanding forests and tree cover.

1.1 Cities, forests, and climate change

Local communities (Box 1)—both rural and urban—have unique policy tools available to implement climate change mitigation strategies. Among them are forest- and tree-based strategies that fall into the broad category of "nature-based solutions." Actions taken by communities, both inside and beyond their borders, will be key to meeting the climate action targets set by national and international agreements, and inclusion of forests and trees in local climate action plans can enhance the adoption of nature-based solutions at all levels. Communities can play an important role in increasing the terrestrial carbon sink, for several reasons:

- Urban trees sequester significant amounts of carbon. In the United States alone, for example, they remove nearly 100 million metric tonnes of CO_2 from the atmosphere each year (Nowak et al. 2013), equivalent to absorbing the annual emissions from 22 million cars, or to the total emissions of many small developing countries (e.g., Paraguay).
- Many peri-urban and rural communities around the world with high forest mitigation potential (reducing emissions and increasing removals) are developing GHG inventories and climate action plans.
- Because such communities contain more than half the world's population, it is helpful for their residents to understand the role of forests and trees in regulating the climate. Raising urban dwellers' awareness of the importance of forests and trees in climate mitigation can increase support in these communities for initiatives that protect, maintain, and restore forest and tree cover locally, regionally, and globally.
- Beyond the carbon storage and sequestration benefits trees provide, increasing urban tree canopy can lower the urban heat island effect through increased shade and evapotranspiration, reduce heat-related illness, lower demand for energy and air conditioning, help protect important watersheds, intercept and store rainwater, support native biodiversity, and remove pollution and sediment loads from stormwater (Bell and Wheeler 2006).

However, many local climate action plans and GHG inventories have not included forests and trees. According to a survey conducted of its member communities by the U.S affiliate of the ICLEI–Local Governments for Sustainability (ICLEI–USA), common reasons that communities have not included forests and trees in inventories are lack of guidance about how to incorporate them into inventories, a perceived lack of data to develop the estimates, perceptions that GHG impacts are insignificant, and political and technical challenges associated with being an "early mover" (ICLEI 2018).

Box 1 What is a community?

As in the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories, the term *community* is used throughout this document to refer to geographically discernible subnational entities, such as towns, cities, provinces, districts, townships, wards, and neighborhoods. It is used to indicate all levels of subnational jurisdiction as well as local government and legal entities of public administration. The term *community* was chosen over *city* to be more inclusive; urban trees can be important sources of CO_2 removals (or emissions), but GHG fluxes associated with forests and trees are also significant for less urbanized communities (e.g., municipalities that include larger rural areas).

1.2 The purpose of this supplement and how it was developed

The ability of communities to take action on mitigating climate change, and to monitor progress, depends on having access to GHG inventory data. Such data enable communities to understand the contribution of different sectors and activities to their GHG profile and how these change through time. Because forest- and tree-related GHG emissions and CO_2 removals (collectively called GHG fluxes) are rarely included in local inventories, many communities have a limited perspective on how their land, and changes to it, influence GHG fluxes. This Global Protocol for Community-Scale Greenhouse Gas Inventories Supplemental Guidance for Forests and Trees (henceforth, the supplement) provides methods for communities to increase their understanding of these fluxes.

This supplement is designed to be used alongside the Global Protocol for Community-Scale Greenhouse Gas Inventories (GPC) (WRI et al. 2021). The GPC helps communities develop a comprehensive and robust GHG inventory that supports climate action planning. The GPC was developed jointly by World Resources Institute (WRI), ICLEI, and the Cities Climate Leadership Group (C40) in 2014 (WRI et al. 2014), with an update released in 2021.

Although the GPC includes the Agriculture, Forestry, and Other Land Use sector (AFOLU) (GPC, Chapter 10),[3] it focuses on emissions (rather than removals) and does not provide detailed methods to estimate emissions from or removals from forests and trees (covered under the "Land" sub-sector of AFOLU). The GPC's "city-induced framework" gives local communities the option of selecting between two reporting levels: BASIC or BASIC+. Owing to the more intensive data collection and calculation processes involved, AFOLU is currently not a required reporting category under BASIC. Inclusion of the AFOLU sector is required under BASIC+ reporting. Communities for which AFOLU emissions are significant and relevant should aim to include these emissions regardless of whether they are reporting BASIC or BASIC+ (GPC, Section 4.1).

In practice, however, many communities that use the GPC do not attempt to or struggle to include emissions and removals due to AFOLU, including the "Land" sub-sector, in their GHG inventories due to the complexities of doing so. While the GPC provides basic information on the "Land" sub-sector (GPC, Section 10.4), cases in which AFOLU removals are significant and relevant for a community are not currently addressed; this supplement is designed to fill this gap and provides inventory compilers with more detailed guidance on calculating both emissions and removals—collectively, GHG fluxes associated with forests and trees—in a community context. It presents a standardized but flexible approach for communities worldwide to measure and account for forests and trees in GHG inventories and climate mitigation goals. It does not cover the "Livestock" sub-sector at all and partially

3. All GPC references are to WRI et al. (2021).

covers the "Aggregate Sources and Non-CO_2 Emission Sources on Land" sub-sector (GPC, Sections 10.3 and 10.5, respectively). (See Section 1.3 of this supplement for further information on its coverage.)

This supplement uses simplified methods designed to be fit for purpose for communities while preserving the detail needed to provide useful GHG inventory information for informing policies regarding climate change mitigation at a community scale. It assumes that users of this supplement are already familiar with the GPC, including inventory principles (relevance, completeness, consistency, transparency, and accuracy), target setting, data quality and uncertainty assessment, and reporting frameworks.

In elaborating upon the GPC's "Land" sub-sector guidance (which, in turn, is based on IPCC guidelines for national greenhouse gas inventories), this supplement builds on a publication written for ICLEI's U.S. Community Protocol (USCP) (ICLEI 2019). Whereas ICLEI's USCP is designed for use by communities inside the United States, this GPC supplement is designed for use by communities worldwide. USCP Appendix J was pilot tested in more than 20 U.S. communities during its development in 2019, and those pilots plus four additional pilots in communities in other countries in 2020 and 2021 have informed this supplement's applicability across a range of community contexts (Box 2).

This supplement has the following objectives:

- Publish methods that enable communities to cost-effectively include forests and trees in their local GHG inventories in a way that helps community leaders and their constituents plan their climate change mitigation actions.

- Create international consistency and transparency in the way communities develop GHG inventories for forests and trees, while recognizing each community's unique circumstances and needs.
- Support the reconciliation of national GHG inventories and subnational monitoring to inform mitigation targets (for example, nationally determined contributions) under the UN Framework Convention on Climate Change (UNFCCC).
- Help cities and other subnational actors understand how forests and trees can contribute to ambitious and transparent climate change mitigation goals.

Box 2 Pilot tests in four communities

The methods and approaches in this supplement were developed alongside simultaneous pilot testing conducted in 2020 and 2021 in four cities in different countries, which built on pilots conducted in more than 20 cities and counties in the United States in 2019. Pilot testing outside the United States was conducted by staff based in WRI's U.S. and international offices in coordination with local government counterparts as part of WRI's Cities4Forests Initiative. These pilots were critical to confirming that the methods apply across a variety of community contexts, geographic regions, and levels of data and resource availability.

While the U.S. Community Protocol's Appendix J and this Global Protocol for Community-Scale Greenhouse Emission Inventories forest and tree supplement were under development, their respective author teams conducted a series of virtual training webinars for all participating pilot communities and provided additional one-on-one technical assistance for each community to guide it through the process of compiling its inventory for the first time. Feedback from pilot participants highlighted potential sources of confusion and challenges. Based on feedback from U.S. communities, an interactive online calculator tool, the Land Emissions and Removals Navigator (LEARN),[a] was built to support U.S. communities in implementing the guidance outlined in USCP Appendix J.[b] A global, automated tool for communities outside the United States was not available at the time of publication.

Four international community pilots

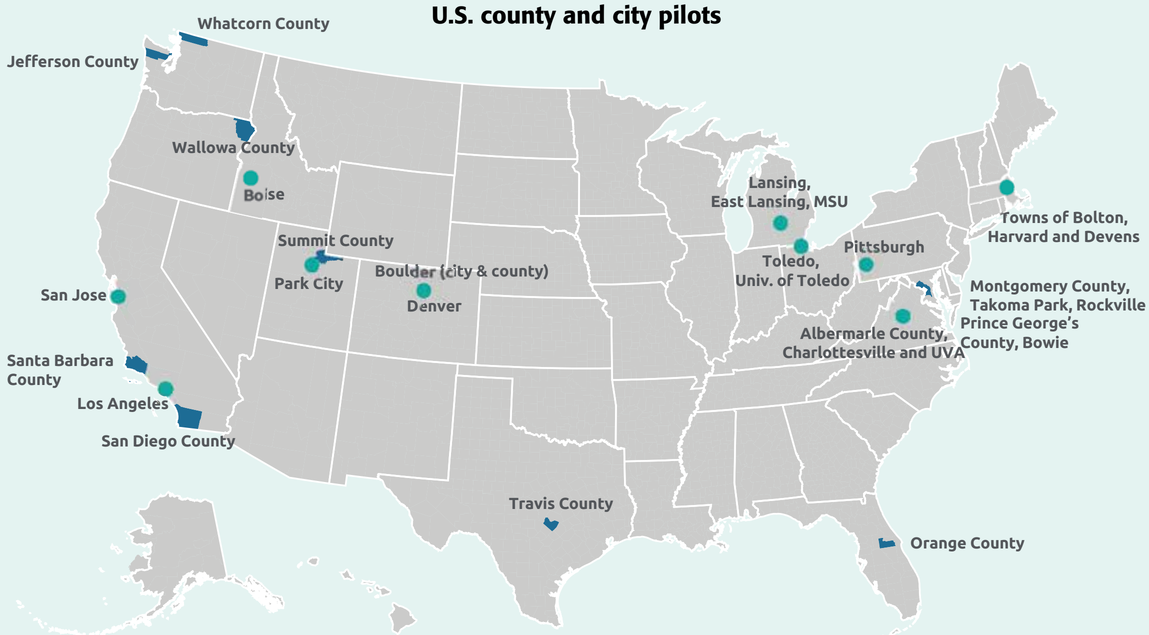
Mumbai, India

Salvador, Brazil

Jakarta, Indonesia

Mexico City, Mexico

U.S. county and city pilots



Notes:
a LEARN tool: https://icleiusa.org/LEARN/.
b US Community Protocol Appendix J: https://us-protocol.pubpub.org/pub/v732gbdy/release/1.
Source: Authors.

1.3 Coverage of this "Land" sub-sector GHG inventory supplement

Although this supplement elaborates on the "Land" sub-sector of the GPC (GPC, Section 10.4), there are several topics on which it does not provide guidance. Table 1 presents the coverage of this supplement.

Table 1 Coverage of this supplement

Topic		The Supplement Covers:	The Supplement Does Not Cover:
GHG component	*Forest Land*	Emissions (biomass and soil) and removals (biomass only) by *Forest Land*, including land-use changes and forest disturbances.	Changes in carbon stored in harvested wood products or substitution effects for harvested wood products, changes in deadwood or litter pools in *Forest Land*.
	Non-Forest Land	Emissions from and removals by trees on *Non-Forest Land* (biomass only).	Nontree aspects of *Non-Forest Land* (e.g., soil carbon changes on agricultural lands or wetlands).
	Soil	Emissions from soil during land-use changes involving *Forest Land* (deforestation).	Carbon sequestered by *Forest Land* soils, and all aspects of managed soils on *Non-Forest Land* (e.g., *Cropland, Grassland, Wetlands*).
	Biomass or residue burning	CO_2 and non-CO_2 emissions from forest fires.	Biomass burning for energy (reported in Stationary Energy sector; GPC, Chapter 6).
	Biomass in landfill	N/A	Any aspect (reported in Waste sector; GPC, Chapter 8).
Scopes		Scope 1 emissions and removals (territorial GHG fluxes).	Scope 3 emissions (e.g., GHG emissions associated with displacement of land development to nearby municipalities due to maintenance or growth of urban tree cover in the inventoried community), indirect impacts beyond Scope 3 (e.g., GHG consequences of land-use change caused by consumption of products within the community).
Approach		Historical GHG emission or removal inventory.	Product GHG life-cycle assessments (e.g., for harvested wood products).
Resources		A framework for communities to understand the magnitude and direction of GHGs from forests and trees. (A link to a sample worked inventory spreadsheet is provided in Appendix D.)	Specific data sources, tools, or inventory calculators.

Table 1 Coverage of this supplement, continued

Topic	The Supplement Covers:	The Supplement Does Not Cover:
Policy relevance	Information that can be used to inform and track climate-friendly policies. Guidance on integrating forest and tree GHGs into the broader GHG inventory and climate action targets.	Estimates that can be used for selling carbon credits (see Box 6). Methods to measure the indirect or non-GHG impacts of forests/trees.
Output	The development of a local GHG inventory consistent with IPCC national inventory methods.	Estimation of the GHG impacts of specific mitigation activities, or projection of GHG fluxes.

Notes: Because more information is available about soil carbon in forests than for other land uses, soil emissions from forest loss are the only GHG flux covered in this supplement.
GHG = greenhouse gas; GPC = Global Protocol for Community-Scale Greenhouse Gas Emission Inventories; IPCC = Intergovernmental Panel on Climate Change.

This supplement follows IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006, 2019b) in that land-related GHGs are reported in six main land-use categories (*Forest Land, Cropland, Grassland, Settlements, Wetlands,* and *Other Land*) and in the equations used.[4] Both emissions and removals can occur in each of these land-use categories and shall be reported separately in GHG inventories that include forests and trees (see Chapter 9 for reporting requirements).

In this supplement, detailed guidance is provided for estimating GHG emissions and CO_2 removals by *Forest Land* and by trees within a community's *Non-Forest Land (Cropland, Grassland, Settlements, Wetlands, and Other Land)*; that is, "trees on *Non-Forest Land*" or "trees outside forests." Collectively, this represents emissions and removals for forests and trees.

- *Forest Land*: This supplement covers GHG emissions resulting from *Forest Land converted to Non-Forest Land* (deforestation) and emissions occurring on *Forest Land remaining Forest Land* resulting from disturbances, such as fires and timber harvesting. It covers removals associated with *Non-Forest Land converted to Forest Land* (afforestation or reforestation) and removals occurring on undisturbed *Forest Land remaining Forest Land*.
- *Non-Forest Land* (*Cropland, Grassland, Settlements, Wetlands, Other Land*): This supplement covers GHG emissions and removals associated with trees on *Non-Forest Land* (i.e., trees outside forests), including urban trees. This is a step toward comprehensive inventory coverage of *Non-Forest Land* GHG fluxes, which would also include guidance for calculating GHG fluxes associated with managed agricultural and wetland soils.

While GHG emissions associated with soil in *Forest Land* are included in this supplement, GHG fluxes associated with soils in *Non-Forest Land* are not covered. This is because, in general, forests and trees (and their associated GHG fluxes) dominate the GHG fluxes of most communities within the "Land" sub-sector (Pan et al. 2011; Harris et al. 2021). Moreover, data are also more widely available for estimating GHGs associated with forests and trees than for estimating agricultural, grassland, or wetland soil GHG dynamics at local scales.

Activities taking place within a community can generate GHG emissions inside the community boundary as well as outside the community boundary. To distinguish among them, the GPC recognizes three categories of emissions based on where they occur: Scope 1, Scope 2, and Scope 3. Table 2 provides definitions adapted from the scopes

4. For clarity, IPCC land-use categories are capitalized and written in italics. Names of sectors are capitalized and set in regular roman type, while sub-sectors are written the same way but enclosed in quotation marks.

framework used in the GHG Protocol Corporate Accounting and Reporting Standard (WRI and WBCSD 2004). The scopes framework helps to differentiate emissions occurring physically within the community (Scope 1) from those occurring outside the community (Scope 3) and from the use of electricity, steam, and/or heating and cooling supplied by grids that may or may not cross community boundaries (Scope 2). Scope 1 emissions (and removals) may also be termed "territorial" emissions (and removals) because they occur within the territory defined by the geographic boundary. This supplement provides detailed methods for estimating Scope 1 emissions from and removals by forests and trees present within the community boundary (Table 1). Scope 3 emissions related to the "Land" sub-sector will be covered in future GPC guidance.

Forests and trees intersect other sectors in a GHG inventory. The interaction is particularly significant with the Stationary Energy sector, such as through the burning of biomass or agricultural residue, and with the Waste sector, through biomass that goes to landfill. Biomass extracted from *Forest Land* is also used to produce harvested wood products that store carbon for various durations, from short periods (e.g., paper) to very long periods (e.g., furniture or in building construction). The substitution effects of using such products can also impact other sectors; for example, using wood for buildings compared to energy-intensive materials such as cement or steel (Industrial Processes and Product Use sector).

Full and accurate estimation of land-use impacts on GHGs requires inclusion of all these linked systems. However, such systems often cross geographic boundaries; for example, wood produced within a community may be used for energy outside the community boundary. Similarly, biomass waste may end up in a landfill within (or outside) the community boundary. In the case of firewood or woodchip burning for energy, CO_2 emissions from biomass losses in a forest often occur in a different community from energy emissions (i.e., non-CO_2 emissions from bioenergy). In other words, the community where the harvesting takes place may see a net loss of biomass (i.e., an emission), whereas the community that is burning bioenergy may see a net GHG benefit from using that biomass due to displacement of fossil fuels.

Table 2 **Definition of scopes for community inventories**

Scope	Definition
Scope 1	GHG emissions from sources (and removals by sinks) located within the community boundary
Scope 2	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam, and/or cooling within the community boundary
Scope 3	All other GHG emissions (and removals) that occur outside the community boundary as a result of activities taking place within the community boundary

Note: GHG = greenhouse gas.
Source: WRI et al. (2021).

Ultimately, indirect emissions due to consumption of products associated with AFOLU emissions occurring outside the community boundary (Scope 3 emissions) should also be addressed, as populations in cities often have a much larger footprint on land beyond emissions and removals occurring on land within their boundaries. While guidance for calculating these Scope 3 emissions is not covered explicitly here or in the main GPC, communities may wish to design analyses that track and report these Scope 3 fluxes as *Other Scope 3*. Other tools can help communities estimate the embodied deforestation consumed in cities, such as the Forest Footprint for Cities tool developed under WRI's Cities4Forests initiative. Alternatively, corporate Scope 3 accounting methods for purchased goods and services, outlined in the forthcoming Greenhouse Gas Protocol Corporate Land Sector and Removals Guidance, could be adapted to cover those from cities and other communities. Ultimately, to support communities' measurement of Scope 3 emissions in a robust and consistent manner, the authors of the GPC expect to provide additional guidance on estimating emissions from key goods and services produced outside the city boundary (WRI et al. 2021).

2 How GHG fluxes on land occur

Land is different from other sectors in a GHG inventory in that it can be either a source or a sink for CO_2. Globally, emissions from AFOLU (primarily from tropical deforestation and management of agricultural land) account for approximately one-fifth of all anthropogenic GHG emissions (IPCC 2019a). At the same time, forests and other terrestrial vegetation absorb about 30 percent of CO_2 emissions from fossil fuels every year (IPCC 2019a). Therefore, the term *GHG emissions* is not broad enough in the land context. *GHG flux* is used to refer collectively to both GHG emissions from land and CO_2 sequestered by land, referred to as CO_2 removals. A flux is simply a flow (here, of greenhouse gases) from one system to another, such as between the land and atmosphere. When completing a community GHG inventory, it is important to consider how land contributes to both GHG emissions and removals.

2.1 CO_2 fluxes

For most sectors of a community's GHG inventory (e.g., Stationary Energy, Transportation, Waste), standard emission factors can be applied to a specific activity to estimate GHG emissions regardless of location; for example, the CO_2 emissions associated with a given quantity of electricity purchased or miles driven. In contrast, the amount of carbon (C) contained on land and cycling through different ecosystems is extremely variable across locations and through time.

Terrestrial carbon is stored in multiple pools, or reservoirs: aboveground biomass, belowground biomass, deadwood, litter, soil, and harvested wood products (Box 3). In many communities, the single largest terrestrial carbon pool is aboveground biomass. The major exception is land with deep organic soils, like peat swamps or mangroves, where soil carbon may be the dominant pool. Carbon in belowground biomass (roots) is often approximately one-quarter of aboveground carbon, but this varies from region to region (Huang et al. 2021). Deadwood and litter carbon may comprise a small percentage of the aboveground carbon, although they can also vary substantially.

Over time, in response to both human activities and natural processes, carbon is transferred among pools and between them and the atmosphere (Figure 1). The total amount of carbon in each pool at a specific time is called its stock (generally reported in units of tonnes C [t C]), while the amount stored per unit land area is the density (e.g., tonnes C per hectare [t C/ha]). Transfers result in changes in carbon stocks. Emissions to the atmosphere and removals from the atmosphere are estimated based on the carbon stock changes in land; emissions result in loss of carbon from land, while removals result in a gain of carbon in terrestrial vegetation and/or soils. Emissions and removals are often referred to as gross CO_2 fluxes, and the and the balance between them is the net CO_2 flux. Net sinks have more gross removals than gross emissions in a specific location and time, while net sources have more gross emissions than gross removals (Table 3). In general, CO_2 is the dominant GHG associated with forests and trees (see Section 2.2 for more information on non-CO_2 fluxes).

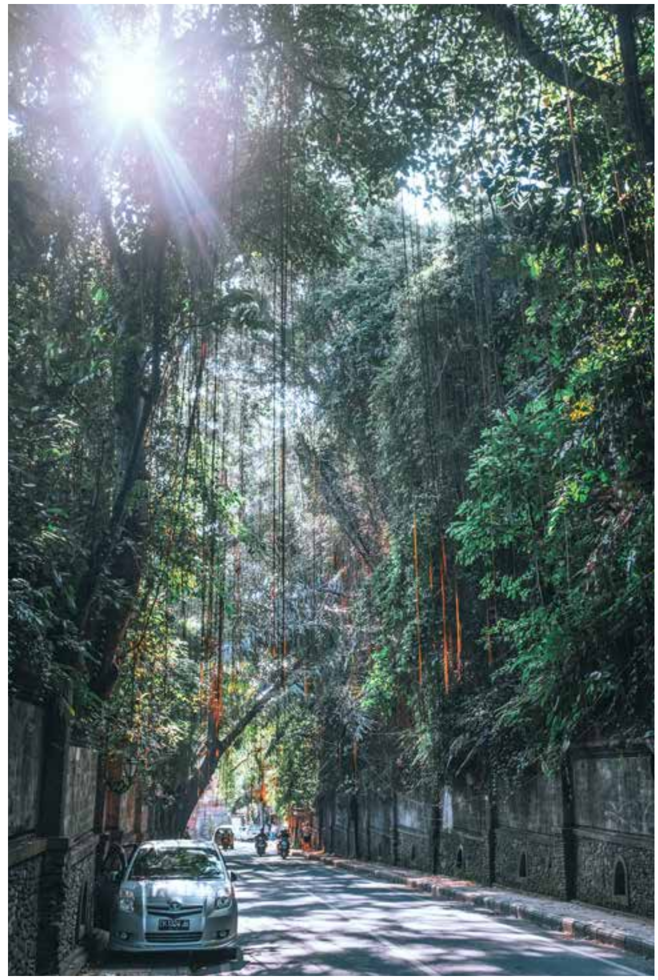


Table 3 Common terminology used to describe GHG fluxes in the "Land" sub-sector

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 net change in stock	Loss	Gain
Reporting convention	Positive number (+)	Negative number (-)

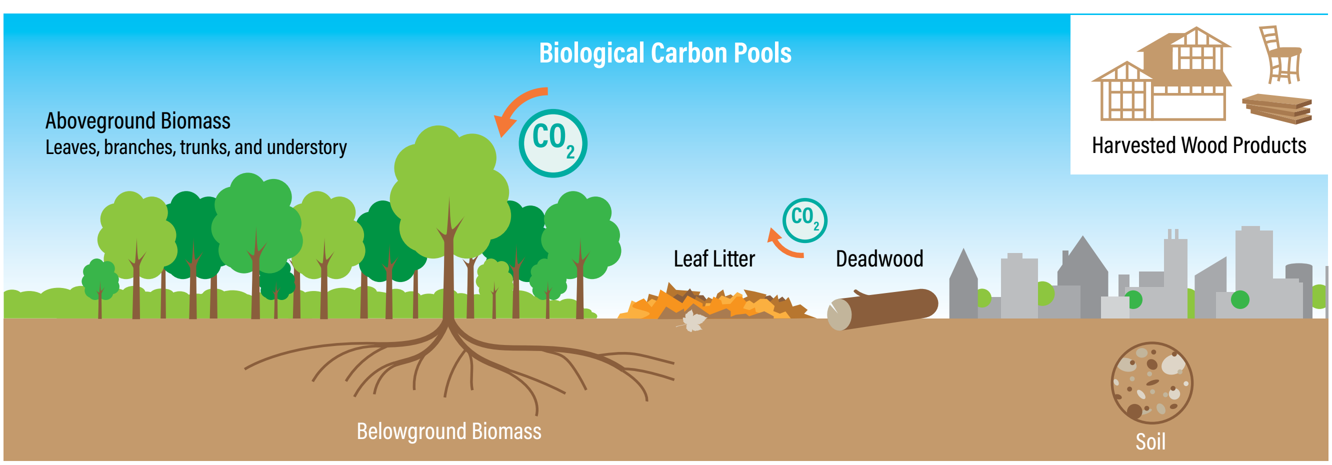
Note: GHG = greenhouse gas.

Box 3 Carbon pools

Carbon on land is stored in five ecosystem pools, or reservoirs. In addition to the carbon stored in the aboveground and belowground biomass of trees, or biomass carbon, carbon is also stored in deadwood, litter, and soil. Additionally, carbon is transferred from ecosystems and stored in a sixth pool of harvested wood products. The six carbon pools as defined by IPCC (2019b) are the following:

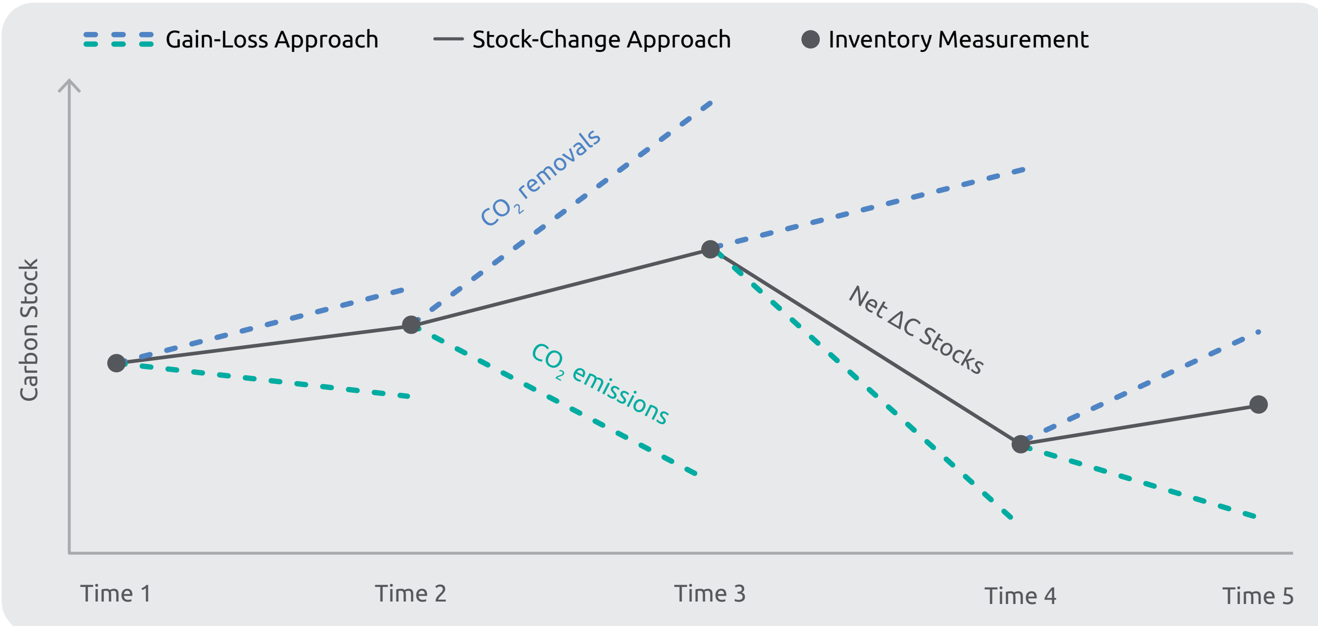
- **Aboveground biomass carbon:** Carbon in biomass of living vegetation, both woody and herbaceous, above the soil, including stems, stumps, branches, bark, seeds, and foliage. About half of the dry weight is carbon, with the other half being water and other compounds.
- **Belowground biomass carbon:** Carbon in biomass of live roots larger than a minimum specified size, often 2 millimeters in diameter. Smaller roots are often excluded because they typically cannot be distinguished from soil organic matter or litter. About half of the dry weight is carbon, with the other half being water and other compounds.
- **Deadwood:** Carbon in nonliving woody biomass not contained in the litter. Deadwood includes standing deadwood, wood lying on the surface, dead roots, and stumps, larger than or equal to the maximum size set for litter (often 10 centimeters in diameter).
- **Litter:** Carbon in all nonliving biomass with a size greater than the limit for soil organic matter (usually 2 millimeters) and less than the minimum diameter chosen for deadwood (e.g., 10 centimeters), lying dead, in various states of decomposition above or within the mineral or organic soil. The maximum size for materials to be included in litter depends on the inventory.
- **Soil organic carbon:** Organic carbon in mineral soils to a specified depth, usually 30 centimeters. Live and dead fine roots and dead organic matter (deadwood and litter) within the soil that are less than the minimum diameter defined for roots and dead organic matter are included in soil organic carbon where they cannot be distinguished from it empirically.
- **Carbon in harvested wood products:** Carbon in all wood material (including bark) that leaves harvest sites. This 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 construction materials, 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.

Figure 1 Carbon pools, CO_2 emissions, and CO_2 removals



Source: Authors.

Figure 2 **Stock-change versus gain-loss methods for estimating terrestrial carbon stock changes over time**



Notes: CO_2 = carbon dioxide; ΔC = change in carbon.
Source: Authors.

To estimate net CO_2 fluxes from land, IPCC national GHG inventory guidelines (IPCC 2006, 2019b) outline two broad methods: the stock-change (or stock-difference) method and the gain-loss method (Figure 2). Both are valid and applicable for communities, although the latter is generally more feasible to apply in a community context based on the data available (GFOI 2016) and therefore is the method recommended by this supplement.

In the stock-change method, net CO_2 fluxes (net changes in carbon stocks) are inferred from the difference in carbon stocks measured at different times across a network of inventory plots. Results are most statistically robust when an adequate number of plots is sampled across the geographic area of interest at many points in time. The IPCC's Good Practice Guidance for Land Use, Land-Use Change, and Forestry (Penman et al. 2003) notes that the stock-change method provides good results where there are relatively large increases or decreases in estimated biomass, or where there are statistically rigorous inventories. The stock-change method can be used where sufficient inventory sample plots have been repeatedly measured over multiple years in or near a community. However, most communities do not have sufficient plot data to use this approach. It also does not allow for the estimation of emissions and removals separately, as required by the GPC. Thus, this supplement does not discuss it further.

The gain-loss method, described in this supplement, is fundamentally like GHG inventories in other sectors in that fluxes are estimated during a given inventory as the product of activity data (an area of categorized land use or land-use change) and emission factors (the amount of carbon emitted by each carbon pool per unit of land area). Unlike other sectors, however, the "Land" sub-sector also includes removals, or sequestration, which are the product of activity data and carbon gain factors. Carbon gain factors are estimated as the amount of carbon accumulated by vegetation per unit area of land use or land-use change per year.[5] For the "Land" sub-sector, activity data include both areas of land that undergo a change in land use, such as *Forest Land converted to Grassland*, as well as land that

5. This supplement uses the term *carbon gain factor* to avoid confusion with the term *removal factor*, which may be associated with technological or biological carbon dioxide removal processes that permanently remove CO_2 from the atmosphere. Here, the carbon gain factor is analogous to the emission factor.

maintains its use over time, such as *Forest Land remaining Forest Land* or *Settlements remaining Settlements*. Emission and carbon gain factors vary by land use and management practice. This method has the advantage of allowing gross emissions and removals to be calculated separately, rather than as a net value as for the stock-change method. Furthermore, inventory plots may only be remeasured on 5- to 10-year cycles, whereas activity data for application of the gain-loss approach (particularly for loss) may be updated more frequently, depending on the availability of monitoring data. This reduces lag time between monitoring when and where emissions and removals occurred and designing appropriate policy interventions to address them.

2.2 Non-CO_2 emissions

Non-CO_2 GHG emissions refer to methane (CH_4) and nitrous oxide (N_2O) emissions that occur from land-use and management activities. Non-CO_2 emissions can occur as a result of fire, nitrogen (N) fertilizer application and other forms of nitrogen management on soils, livestock management, rice cultivation, and wetland management (Box 4). Other gases included in the GPC—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3)—do not apply to the "Land" sub-sector. Among non-CO_2 gases, this supplement only provides guidance for calculating emissions associated with fire. For communities interested in estimating non-CO_2 emissions associated with activities occurring on managed agricultural lands, refer to the GPC, Sections 10.3 and 10.5.

Box 4 Sources of non-CO_2 GHG emissions on land

Fire: In the case of prescribed fires or wildfires, burning biomass releases CO_2, CH_4, N_2O, and other precursors that later form GHGs—namely, CO_2, CH_4, CO, nonmethane volatile organic compounds, N_2O, and NO_x. 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 calculation of non-CO_2 greenhouse gas emissions (doing so would lead to double-counting of emissions). The volumes of the other gases and their equivalency to CO_2 are estimated to determine the impact of biomass burning on total anthropogenic GHG emissions.

Landfill waste: Emissions from CH_4 and N_2O as decomposition in landfills are reported in the Waste sector of the inventory rather than the "Land" sub-sector; guidance on their estimation is not provided in this supplement but can be found in the GPC.

Bioenergy combustion: Burning biomass for bioenergy releases CO_2, CH_4, N_2O, and other precursors. CO_2 emissions are factored into the calculation of carbon stock changes for the pools that are oxidized. The volumes of the other gases and their equivalency to CO_2 are reported in the Energy sector of the inventory rather than the "Land" sub-sector; guidance on their estimation is not provided in this supplement but can be found in the GPC.

Nitrogen management, rice cultivation, and livestock management: These emission sources are reported under the "Livestock" and "Aggregate Sources and Non-CO_2 Emission Sources on Land" sub-sectors rather than the "Land" sub-sector; guidance on their estimation is not provided in this supplement but can be found in the GPC's Chapter 10.

Wetland management: Non-CO_2 emissions from wetlands 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. Owing to the complexity and site-specific nature of their calculation, general guidance for estimating these fluxes is not provided in this supplement.

Notes: CO = carbon monoxide; CO_2 = carbon dioxide; CH_4 = methane; N_2O = nitrous oxide; NO_x = nitrogen oxides; GHG = greenhouse gas; GPC = Global Protocol for Community-Scale Greenhouse Gas Emission Inventories.

3 Overview of steps for estimating land-based fluxes for the GHG inventory

The first step of a GHG inventory for *Forest Land* and trees on *Non-Forest Land* is to delineate the geographic boundary used to represent a community's land base according to its relevant land-use classes (Chapter 4). Once this step is complete, there are four broad stages to compiling a basic GHG inventory for forests and trees (Figure 3). The first three stages are performed separately for *Forest Land* (Chapter 7) and trees on *Non-Forest Land* (Chapter 8), while the fourth stage (Chapters 9 and 10) may be done with combined forest and tree GHG fluxes. For the most part, the *Forest Land* and trees on *Non-Forest Land* inventories can be conducted in parallel.

Stage 1. Explore and select data sources (the "data selection cycle")

Stage 2. Prepare and assign activity data, emission factors, and carbon gain factors

Stage 3. Calculate, sum, and annualize GHG fluxes

Stage 4. Incorporate results into the broader GHG inventory and climate action targets

In Stage 1, data sources are chosen for the activity data and emission or carbon gain factors used for an inventory (detailed in Chapters 4–6 and summarized in Chapters 7 and 8 for completeness). These choices often depend on each other. Identifying, understanding, and reconciling disparate data sources, for both *Forest Land* and trees on *Non-Forest Land*, may be one of the most challenging and time-consuming parts of developing the inventory. In particular, choosing activity data with corresponding emission and carbon gain factors for a specific inventory may require multiple iterations. This is especially true for communities that are including forests and trees in their inventories for the first time. Data can be refined from one inventory cycle to the next, particularly for the activity data.

In Stage 2, activity data are compiled and calculated (hectares of forest and tree canopy lost, gained, and maintained) (Chapters 7–8). Activity data can be corrected at this stage to adjust for temporary (instead of permanent) losses of forest cover that do not constitute a change in forest land use. Emission and carbon gain factors are also matched to the activity data at this stage.

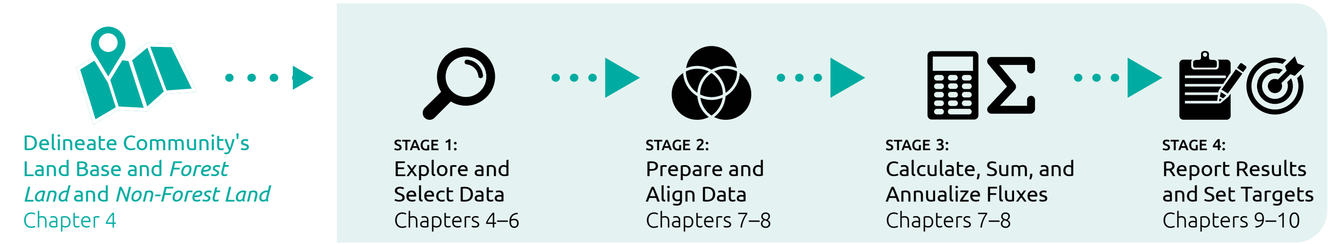
In Stage 3, gross emissions and removals for different land use and land-use change categories are calculated, then aggregated into an estimate of total net GHG fluxes associated with *Forest Land* (Chapter 7) and trees on *Non-Forest Land* (Chapter 8) during an inventory cycle. Depending on the land uses and changes present within a community, this should include CO_2 emissions and removals, non-CO_2 emissions, and the GHG net flux.

In Stage 4, results for the "Land" sub-sector, that is, GHG fluxes from forests and trees, are incorporated into the GHG inventory alongside other sectors (e.g., Stationary Energy, Transportation, Waste) (Chapter 9) and can be used to develop or revise a community's climate action targets (Chapter 10). The ways land is accounted and incorporated into mitigation goals will depend on the community's unique circumstances and goals.

Both Chapter 7 (*Forest Land*) and Chapter 8 (trees on *Non-Forest Land*) outline a series of numbered technical "steps" intended to guide an inventory compiler through the process of completing the inventory. Depending on a community's land-use profile (e.g., highly urbanized cities with little forest area), there may be no *Forest Land* to include in an inventory, and only the estimation of GHG fluxes for trees on *Non-Forest Land* (including urban tree canopy) in Chapter 8 will be relevant. For extensively forested communities, most of the "Land" sub-sector GHG fluxes may come from *Forest Land* rather than trees on *Non-Forest Land*.

A full forest and tree inventory workflow is shown in Appendix B, and a worked example of a GHG inventory for forests and trees is available for download in Appendix D.

Figure 3 Overview of steps for compiling a GHG inventory for forests and trees



Source: Authors.

PART II
Setting up the inventory

Part II of this supplement supplies guidance for inventory compilers about how to set up the inventory for forests and trees—including how a community's land shall be delineated and represented as subcategories in the inventory (Chapter 4), considerations for how frequently GHG fluxes from land can and shall be updated and reported (Chapter 5), and the data needed (Chapter 6) to implement the calculation guidance in Part III for *Forest Land* (Chapter 7) and trees on *Non-Forest Land* (Chapter 8). As with Part I, Part II will be particularly helpful for communities that are including forests and trees in their inventory for the first time.

4 Representing land in the inventory

How a community's land is represented in the inventory and the data available for this representation are both critical for how emissions and removals—and thus net changes in carbon stocks—occurring on those lands are estimated and tracked through time. The level of aggregation or disaggregation that a community provides with respect to its land base will influence a community's understanding of what mitigation actions and policies may be effective in which places for changing the trajectory of emissions and removals associated with forests and trees.

4.1 Delineating the community's land base

Guidance on establishing the geographical boundary for a community's inventory is provided in the GPC's Section 3.1. This corresponds to the beginning of Figure 3. By default, all land inside a community's boundary should be considered managed (Box 5) and included in the inventory, with emissions and removals reported under Scope 1. The GPC's reporting requirements state that a community's boundaries remain the same from inventory to inventory to facilitate comparison between inventories. Therefore, if the community boundary changes prior to a follow-up inventory (e.g., territory annexed), previous inventories shall be recalculated using the new land base. The same data should be available for the entire inventory area and the entire inventory cycle.

There are a few additional situations for communities to consider:

- Areas outside the boundary that the community owns, manages, or influences may be included in the inventory, but they shall be reported separately as Other Scope 3 (GPC, Section 4.1). This includes areas directly influenced by the community's planning decisions.
- Areas inside the GHG accounting boundary where local land-use policies do not apply, such as national parks or areas managed by carbon project developers (Box 6), shall be included in the community boundary, but their fluxes may be tracked and reported separately to provide context for the community's inventory. Reporting GHG fluxes separately from any land requires justification and documentation of the boundaries involved.

Box 5 Managed versus unmanaged land

IPCC guidelines for national GHG inventories (IPCC 2006, 2019b) 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 land was developed to separate the effects of anthropogenic (human-caused) activities from non-anthropogenic (natural) effects on GHGs.

In practice, separating natural from human-caused emissions or removals is 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. While some national inventories distinguish between managed and unmanaged lands, many do not (Ogle et al. 2018). Communities should consider all land as managed. Where a portion of community land is designated as unmanaged and excluded from the inventory, justification shall be provided on the methods used to delineate the unmanaged land and geospatial boundaries shall be provided in documentation.

Notes: GHG = greenhouse gas; IPCC = Intergovernmental Panel on Climate Change.

Box 6 Communities with nature-based solution activities generating carbon credits in the greenhouse gas accounting boundary

Carbon markets continue to evolve, particularly voluntary carbon markets. Over the next several years, NBS credits may be generated at the scale of state, provincial, or national "jurisdictions" and/or as nested projects within a jurisdiction, and they may be traded domestically and/or internationally, by governments and/or the private sector, for compliance and/or voluntary markets.

While less of a concern for cities, communities with substantial forest areas (particularly in developing countries) are faced with a complex and confusing landscape of data and methodological requirements for estimating GHG fluxes associated with forests and trees. As stated in Section 1.3, this supplement is not designed to help communities develop GHG estimates that can be used to generate and sell carbon credits. Separate carbon-crediting standards and their associated methodologies, such as Verra and the Climate Action Reserve, can be used for that purpose. Instead, this supplement is designed to help communities understand the role their lands play in the national GHG inventory and in contributing to local (and national) GHG mitigation outcomes that could arise from changes made to local land-related policies and practices.

In cases where carbon credits are generated by NBS activities occurring within the community's inventory boundary, communities should continue to include these lands in the GHG inventory. This is because, in cases where emission reductions and removals are transferred from one country to another and/or used to fulfill compliance obligations, these will be reconciled by national governments under the Paris Agreement via "corresponding adjustments" to avoid any given emission reduction or removal being counted more than once toward nationally determined contributions. In cases where emission reductions and removals originating in the community boundary are sold on the voluntary market, these shall be reported separately. Communities should track lands accounted under different voluntary crediting systems separately to provide context to the inventory. It is possible that GHG estimation results from the community inventory for these project areas will differ from the baseline and monitoring results generated for crediting purposes, due to differences in data and quantification methods applied. Regardless, communities shall report any credits bought or sold separately from their inventory (GPC, Chapters 4 and 11).

Notes: GHG = greenhouse gas; NBS = nature-based solutions.

4.2 Representing the community's land base as land-use categories

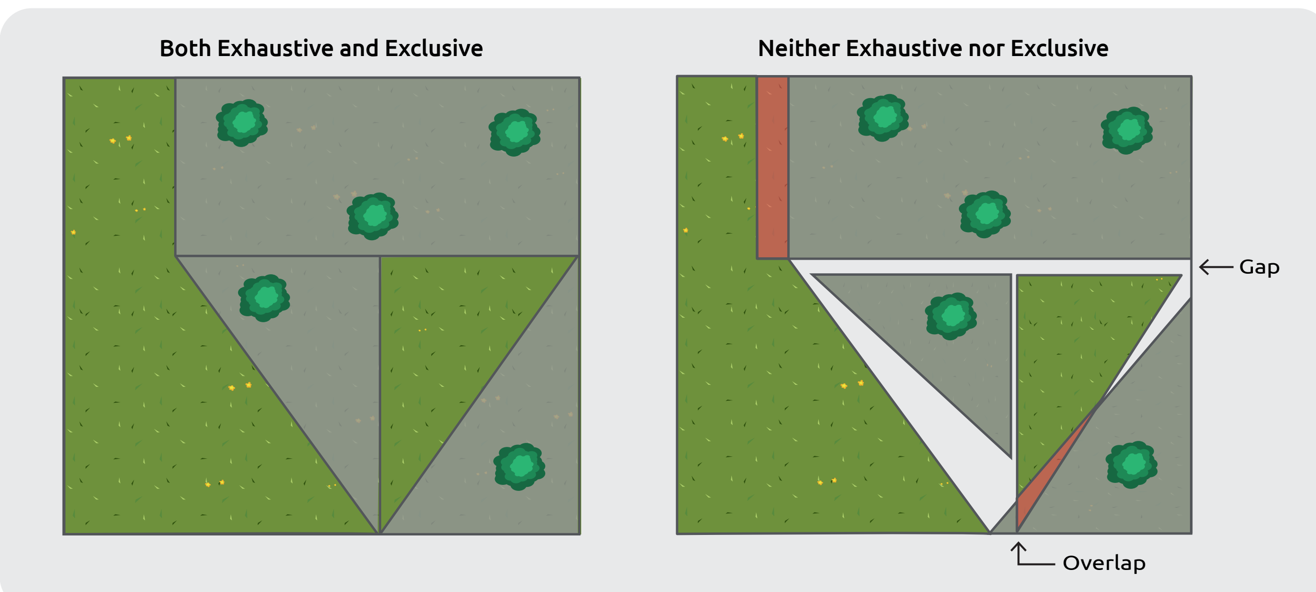
Once a community's GHG inventory boundary has been delineated, it shall be classified into subcategories according to the IPCC's six land-use categories: *Forest Land, Cropland, Grassland, Wetlands, Settlements,* and *Other Land*. The GPC's definitions of these are provided in Box 7. Communities should align their land-use categories and definitions with those of existing national, state, or provincial inventories to facilitate consistency with national, state, or provincial reporting. However, communities may decide to use a different system or definitions if they have compelling reasons, such as that the national, state, or provincial system does not fit the community, is not consistent with the community's laws, will not provide the desired actionable information for the community, or will not facilitate land or GHG management.

Regardless of what land-use classification is employed, the categories shall exhaustively and exclusively divide the community's land into land uses (Figure 4):

- Exhaustively assigning land means that no land is omitted, thereby avoiding undercounting of emissions and removals.
- Exclusively assigning land means that no land is assigned to two categories, thereby avoiding double-counting of emissions and removals.

Land use in a community's inventory area can be estimated using sample-based or map-based approaches. Sample-based approaches examine a statistically meaningful sample of points within the inventory boundary to produce land use and land-use change area statistics for the area of interest, but they do not result in a map of the community's land uses. Map-based approaches use wall-to-wall (complete coverage) maps of land use and land-use change within the inventory boundary. While both approaches can also be used to track land-use change, each has advantages and disadvantages (Table 4). This supplement only further considers map-based approaches for estimating land use and land-use change because of their greater accessibility to communities and the additional value that geospatial information can provide for understanding where activities

Figure 4 **Comprehensive coverage of a community's land base**



Note: Land uses exhaustively and exclusively classify all land within an area in the left panel. Green polygons represent *Forest Land* and gray polygons represent all other land uses. Trees on *Non-Forest Land* are shown in darker green. Land uses overlap (red areas) and omit (white areas) in the right panel.
Source: Authors.

Table 4 Advantages and disadvantages of sample-based and map-based approaches to estimating land use and land-use change

Land-Use Approach	Advantages	Disadvantages
Sample-based	• Can customize land-use categories specifically for inventory • Data are generated locally, potentially through a community or participatory process • Can be performed in a statistically rigorous way that supports quantitative uncertainty analysis of land use and land-use change	• Requires technical proficiency to sample inventory area • Only estimates area of land use and land-use change, not the location of land uses (no wall-to-wall map created) • Community must resample the inventory boundary for each inventory cycle
Map-based	• Wall-to-wall maps support visualization and communication of land use within inventory boundary • May be available from national data or other community projects • Maps locations of land use and land-use change within the inventory boundary, which facilitates mitigation activities	• May not have the statistical rigor of sample-based approaches until an accuracy assessment has been performed explicitly for the community boundary • May not have all the desired land-use classes for the inventory • A comparable map must be created for each inventory cycle

and associated GHG fluxes have occurred within the community; additional information on sample-based approaches can be found in FAO (2016).

Where land could fall into multiple land uses (e.g., an agroforestry system could be *Cropland* or *Forest Land*), one land use must be assigned. The GPC prescribes a hierarchy of *Settlements* > *Cropland* > *Forest Land* > *Grassland* > *Wetlands* > *Other Land*. Assigning land to land units rather than areas of activity divides the land base exhaustively and exclusively. For example, both cattle grazing and forest management activities could occur in the same area but would be assigned as *Forest Land* using the above hierarchy. As another example, forested wetlands would be classified as *Forest Land* rather than *Wetlands*.

The same land-use definitions shall be applied consistently throughout the inventory so that changes in definitions do not appear in the inventory as land-use changes as could occur, for example, through comparing different land-cover or land-use maps produced with different classification methods for different years. If land-use definitions are changed in a follow-up inventory, the changes shall be retroactively applied to previous inventories and the inventories recalculated.

To comply with GPC reporting guidelines, community inventories shall apply land-use definitions, not land-cover ones. The distinction between these, and the consequences of using land cover instead of land use, are explained in Box 8. Although land cover is often easier to map than land use because it is observable with satellite imagery, it is not immediately useful for inventories. Inferring land use from land cover could result in attributing GHG fluxes to the wrong land-use category. Communities can use supplementary data and information to ascertain whether or not observed changes in land cover correspond to changes in land use.

Box 7 Land-use definitions in the Global Protocol for Community-Scale Greenhouse Gas Inventories

The GPC uses the six land-use classes from the Intergovernmental Panel on Climate Change, which are defined in the following hierarchy (highest priority to lowest priority) in case of overlap:

- *Settlements:* All developed land, including transportation infrastructure and human settlements of any size
- *Cropland:* Cropped land, including rice fields, and agroforestry systems where the vegetation structure falls below the threshold for forest land
- *Forest Land:* All land with woody vegetation consistent with thresholds used to define forest land in national inventory
- *Grassland:* Rangelands and pasture land that are not considered cropland, and systems with woody vegetation and other nongrass vegetation that fall below the threshold for *Forest Land*
- *Wetlands:* Areas of peat extraction and land that is covered or saturated by water for all or part of the year
- *Other Land:* Bare soil, rock, ice, and all land areas that do not fall into any of the other five land-use categories

Box 8 Land use versus land cover

Land use refers to the way 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 (Di Gregorio and Jansen 2005). *Land-use change* refers to a change in the use or management of land by humans. *Land cover* refers to the physical and biological attributes of land (such as whether there are trees); it may not always be consistent with the use of the land. For example, an area can have a *Forest Land* use but be temporarily unstocked and therefore have a land cover with few or no trees. 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 Land* to *Grassland* may reflect a temporary disturbance (e.g., harvest), after which the forest is expected to regrow. Assigning such an area to land-use change could result in the incorrect assignment of emission and carbon gain factors.

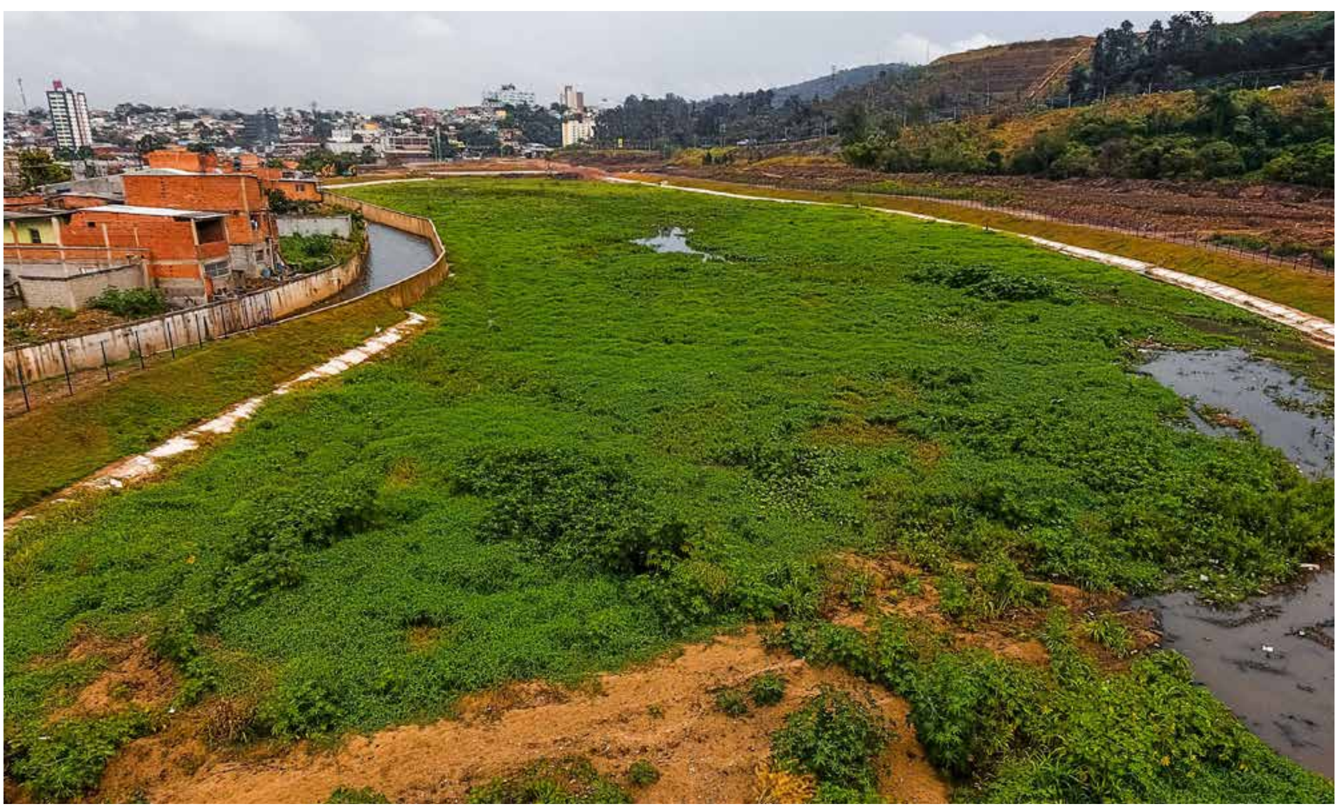
For community-scale inventories, it may be a reasonable simplification—in the absence of additional data and/or to simplify the GHG inventory for lands—to use land cover as a proxy for land use. However, without additional information on land use it is not possible to know whether a land-cover change is temporary or permanent. Therefore, supplementary data and information should be used whenever possible to ascertain whether an observed change in forest cover during the inventory does in fact correspond to a change in land use. This can be done using a combination of local knowledge or expert judgment, site visits, and/or high-resolution satellite or aerial imagery from the year the change was observed (and years prior to and following the change, if available). 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.

4.3 Representing land-use change

Land use at a specific time can provide information on how much carbon is stored at that time, but this information is not immediately useful for a GHG inventory because it cannot be used to estimate changes in land use over time, or how carbon stocks have changed. Conversion between land uses and the maintenance of land use over an inventory cycle are both critical parts of the "Land" sub-sector's activity data, which the GPC defines as "a quantitative measure of a level of activity that results in GHG emissions [or removals] taking place during a given period of time." It is analogous to the miles driven by vehicles, the tons of coal combusted, or the number of livestock for other sectors, although in those cases it is not the change over time that constitutes the activity data.

Although land-use change can be calculated from nonspatial tables of land-use areas at the start and end of the inventory cycle (such as from sample-based approaches [Table 4]), geospatial data are increasingly used for estimating activity data in land-related GHG inventories. Compared to nonspatial tables, geospatial data (e.g., automated processing of satellite data, manual delineation of aerial imagery, and participatory community mapping) provide more granular information about the types, locations, and attribution of land-use changes that are useful for informing climate action, and thus this supplement recommends the map-based approach for calculating land-use change. This entails using at least two land-use maps to develop a land-use change matrix (Table 5), with the entire inventory area divided among the six IPCC land-use classes for the beginning and end of each analysis cycle, such that all land included in the inventory is assigned to one of 36 possible land-use change categories. A separate land-use change matrix is created for each inventory cycle.

Land staying in the same land-use category throughout an inventory cycle (cells outlined in blue on the diagonal of Table 5) is just as important as land-use change; emissions and removals occur in land that maintains the same land use throughout the inventory. Communities with relatively stable land use are likely to have their GHG fluxes concentrated in the diagonals of Table 5, where the top-left cell represents *Forest Land remaining Forest Land* and the remaining diagonal cells represent trees on various subcategories of *Non-Forest Land*:



- Substantial removals can occur in a community's *Forest Land remaining Forest Land*. For example, old-growth forests that remain undisturbed over the inventory may store and remove substantially more carbon than any other land use in the community.
- Emissions can occur from a change of condition in *Forest Land remaining Forest Land*, such as disturbance or management.
- Changes to tree canopy within the *Settlements remaining Settlements* and other diagonal cells can result in emissions from loss of tree canopy and removals due to or resulting from maintaining and/or increasing the *Non-Forest Land* tree canopy area over time.

Table 5 6x6 category land-use change matrix

Land use at start of inventory cycle	Land use at end of inventory cycle →	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*

Forest Land remaining Forest Land

Non-Forest Land converted to Forest Land

Land use stayed the same use during the inventory

Forest Land converted to Non-Forest Land

Non-Forest Land remaining Non-Forest Land on which changes to trees on *Non-Forest Land* are tracked

Note: Each cell represents the area of land that started in a given land-use category and ended in a given land-use category over an inventory cycle.

4.4 Simplified and disaggregated land-use change matrices

After communities categorize their land by the six IPCC land-use categories illustrated in Table 5, they may choose to combine and/or split land-use categories.

Communities can combine multiple land-use categories that are not individually relevant to their inventory to make a simplified land-use change matrix. At the extreme, a community may aggregate its land tracking from a 6x6 land-use change matrix (Table 5) into a 2x2 *Forest Land / Non-Forest Land* change matrix (Table 6). This approach is particularly relevant for communities that have activity data available only for *Forest Land* and *Non-Forest Land* classes. Within the "Land" sub-sector of a community's inventory, forest- and tree-related GHG fluxes are relevant in four subcategories:

1. Standing forests (i.e., *Forest Land remaining Forest Land*), which continue to grow and remove carbon from the atmosphere but can also undergo natural and/or anthropogenic disturbances that cause emissions.
2. Deforestation (*Forest Land converted to Non-Forest Land*), when an area of *Forest Land* undergoes a land-use change; for example, to urban development or new cropland; this leads to emissions because carbon stocks declined during the inventory cycle.
3. New forests (*Non-Forest Land converted to Forest Land*), such as reforesting abandoned croplands, which results in CO_2 removals from the atmosphere.
4. Other *Non-Forest Land* uses and changes, such as *Cropland converted to Grassland*, can also result in emissions or removals depending on the extent to which tree cover or soil carbon increased or decreased on those lands. Only changes in tree biomass are covered in this supplement (Table 1).

Communities may also wish to split up some land-use categories in their 6x6 land-use change matrix, where one land use or land-use change category is disaggregated into multiple subcategories, such as land ownership or forest type. This is analogous to subdividing the "Manufacturing Industries and Construction" sub-sector into detailed subcategories (iron and steel, nonferrous metals, chemicals, etc.; see GPC, Table 6.4).

Land-use change matrices can also be simultaneously simplified and disaggregated. For example, limitations on available land-cover change data in a community context may force the community to aggregate its land tracking into a 2x2 land-use change matrix (*Forest Land / Non-Forest Land*), but other data sources specific to the *Forest Land* category may allow further subdivision of the *Forest Land remaining Forest Land* category into multiple subcategories, enabling different emission and carbon gain factors to be matched to relevant areas of different forest types (Table 7). Further discussion on creating subcategories for *Forest Land* and *Non-Forest Land* is provided in Chapters 7 and 8, respectively.

Table 6 Simplified land-use change matrix

		Land Use at End of Inventory Cycle	
		Forest Land	*Non-Forest Land*
Land Use at Start of Inventory Cycle	*Forest Land*	*Forest Land remaining Forest Land* (Chapter 7)	*Forest Land converted to Non-Forest Land* (Chapter 7)
	Non-Forest Land	*Non-Forest Land converted to Forest Land* (Chapter 7)	*Non-Forest Land remaining Non-Forest Land* (Chapter 8)

Forest Land remaining Forest Land

Forest Land converted to Non-Forest Land

Non-Forest Land converted to Forest Land

Non-Forest Land remaining Non-Forest Land on which changes to trees *on Non-Forest Land* are tracked

Land use stayed the same use during the inventory

Note: Each cell represents the area of land that started in a given land-use category and ended in a given land-use category over an inventory cycle.

Table 7 Sample land-use change matrix where *Forest Land* is disaggregated

		Land Use at End of Inventory Cycle			
		Forest Land Primary	*Forest Land* Secondary	*Forest Land* Plantation	*Non-Forest Land*
Land use at start of inventory cycle	*Forest Land* Primary	*Primary Forest remaining Primary Forest*	*Primary Forest converted to Secondary Forest*	*Primary Forest converted to Forest Plantation*	*Primary Forest converted to Non-Forest Land*
	Forest Land Secondary	*Secondary Forest converted to Primary Forest*	*Secondary Forest remaining Secondary Forest*	*Secondary Forest converted to Forest Plantation*	*Secondary Forest converted to Non-Forest Land*
	Forest Land Plantation	*Forest Plantation converted to Primary Forest*	*Forest Plantation converted to Secondary Forest*	*Forest Plantation remaining Forest Plantation*	*Forest Plantation converted to Non-Forest Land*
	Non-Forest Land	*Non-Forest Land converted to Primary Forest*	*Non-Forest Land converted to Secondary Forest*	*Non-Forest Land converted to Forest Plantation*	*Non-Forest Land remaining Non-Forest Land*

Forest Land remaining Forest Land

Forest Land converted to Non-Forest Land

Non-Forest Land converted to Forest Land

Non-Forest Land remaining Non-Forest Land on which changes to trees *on Non-Forest Land* are tracked

Land use stayed the same use during the inventory

Note: Forest Land has been disaggregated into three subcategories, and all *Non-Forest Land* has been aggregated into one category, with each cell representing the area of land that started in that land-use category and ended in that land-use category.

There is no single correct way to divide the land base, and there are advantages and disadvantages of simplification as well as disaggregation (Table 8; see Case Study 1 and Case Study 2). Communities should determine the appropriate level of aggregation or disaggregation for their inventory early in the inventory compilation process, which may be informed by jurisdictional or governance considerations, or community goals related to land, forests, and/or climate. The extent to which land uses should be disaggregated depends on the available data, how the inventory information will be used, and the community's interests. Depending on the choices made for stratification, some cells of the land-use change matrix may have zero values (e.g., *Non-Forest Land converted to Primary Forest* in Table 7). Regardless of the stratification, subcategories shall comprehensively and exclusively divide up the inventory area.

Table 8 Advantages and disadvantages of simplifying and disaggregating land-use classes

	Advantages	Disadvantages
Simplifying	1. Simplifies calculations because the inventory includes fewer land subcategories to track. 2. Fewer data needed because there are fewer kinds of activity data.	1. Reporting is less detailed because fewer land subcategories are tracked. 2. Inventory may be less accurate because emission and carbon gain factors specific to different subcategories of activity data are not used.
Disaggregating	1. Improves the quality of the inventory and reduces its uncertainty by including emission and carbon gain factors that are specific to each subcategory. • This is beneficial when carbon stocks are highly variable across different forest types within a community or when different types of land management have very different impacts on GHG fluxes. • Different *Forest Land* areas can be combined with distinct emission and carbon gain factors that vary based on forest type or management practice, which ultimately influence the final GHG flux estimates and allow for more detailed reporting (Case Study 1). This requires additional data and changes to the calculations. 2. Provides additional detail in reporting, community engagement, and informing action by focusing attention on or tracking progress in specific land areas of interest to the community. • This use of subcategories requires no additional emission or carbon gain factors; the same emission and carbon gain factors are applied to all subcategories as if disaggregation did not occur. • In this case, reporting is split among additional subcategories relevant for climate action planning, but the total fluxes are the same. • Communities would do this if they were interested in reporting GHG fluxes for specific areas within the community boundary to target interventions or engage specific stakeholders (Case Study 2).	1. If the goal is to improve the accuracy and precision of flux estimates through the development of different emissions and carbon gain factors for each subcategory, additional emission and carbon gain factors are needed. 2. Delineations of relevant subcategories are required and the inventory becomes more complicated due to the introduction of additional categories.

Note: GHG = greenhouse gas.

Case study 1 Stratification of forests from pilot in Salvador, Brazil

This case study illustrates how the use of subcategories for Forest Land *improved the quality of the inventory by being paired with corresponding emission and carbon gain factors.*

Salvador is situated on the east coast of Brazil in the Atlantic Forest biome. Despite Salvador's high level of urbanization and being home to more than 3.4 million people, there are patches of remnant primary Atlantic Forest on Frades Island in the Bay of All Saints (Turubanova et al. 2018).

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

WRI Brasil obtained land-use change data for the inventory cycle (2014–18) from national, freely available sources such as MapBiomas* and Banco de Dados de Informacões Ambientais (BDia)**. Discussions with Salvador city government identified the existence of primary forests on Frades Island, which was not reflected in other national land data being used.

Based on the BDia forest type map, Salvador's *Forest Land* was stratified into three categories (fluviomarine-influenced vegetation, marine-influenced vegetation, and other forest). A fourth, exclusive category of primary forest from Turubanova et al. (2018) was overlaid on the BDia forest type map. All forest types except primary forest had corresponding emission factors in the Atlantic Forest biome section of Brazil's Fourth National Communication to the UN Framework Convention on Climate Change. The Fourth National Communication did not have a primary forest emission factor for the Atlantic Forest biome, so the emission factor for the most similar forest type was used as a proxy. The Fourth National Communication had removal factors for all four forest types, so these were used in the inventory. The Fourth National Communication was selected as the source for emission and removal factors because it is a nationally respected document, it reflects the latest data from Brazil, and it has factors that matched the *Forest Land* subcategories being used. Using these four forest categories with corresponding emission and removal factors produced a more locally relevant inventory than if all forest types had used the same emission and removal factors.

Relevance of the pilot for the Salvador city government:

In 2022, Salvador will complete a new inventory for 2019–20 and is considering using the methodology used for this pilot inventory. The city also intends to update its 2014–18 inventory with this pilot. Salvador has announced its 2050 zero-carbon city goal, and the results of this pilot inventory and the revised methodology presented in this supplement will help the city understand the role that forests, trees, and land use can play in achieving that goal.

* https://mapbiomas.org/.

** https://bdiaweb.ibge.gov.br/.

Case study 2 Stratification of urban tree cover by ward from pilot in Mumbai, India

This case study illustrates how the use of subcategories for trees on Non-Forest Land *did not change the resulting flux estimates but did improve the use of the inventory for communication.*

Mumbai is one of the world's largest cities and is at high risk from the impacts of climate change. Extreme heat, extreme rainfall leading to flooding (both pluvial and riverine), and sea-level rise threaten more than 12 million residents. In response, Mumbai has developed a Climate Action Plan and is exploring the role that its forests and trees play in mitigating the impacts of climate change. As with many megacities, tree cover in Mumbai is not distributed evenly among the city's wards, with wealthier areas enjoying higher canopy cover than lower-income areas.

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

Because tree cover is so unevenly distributed across the city's 24 wards, a single city-scale analysis of trees on *Non-Forest Land* and associated GHG fluxes would omit important socioeconomic context and equity considerations. Obtaining urban tree canopy activity data for each ward (versus aggregated at the city level) was therefore deemed more beneficial for climate action planning. As such, WRI India collected data on change in trees on *Non-Forest Land* in Mumbai using a tool called i-Tree Canopy (USDA Forest Service 2021)* for each individual ward for two inventory cycles (2010–16 and 2016–21). This tool allows users to interpret free satellite imagery at randomly placed points, thereby estimating tree canopy (including in *Non-Forest Land*) and change in that canopy over time. In total, over 12,000 points were interpreted to estimate tree cover and change in Mumbai's wards, with an average standard error of 2 percent (at 95 percent confidence).

Although each ward was included as its own *Non-Forest Land* subcategory with distinct activity data, the same emission and removal factors were applied in every ward. Collecting data on trees on *Non-Forest Land* for each ward essentially allowed a distinct greenhouse gas inventory for each ward, which is more useful for site- and intervention-specific climate action planning and for monitoring changes in tree cover by ward. This also supports a more equitable approach to increasing tree cover in every single ward, rather than as a coarsely aggregated target across the entire city, which may be disproportionately achieved by large gains in the city's wealthiest wards and minimal gains in other areas.

Relevance of the pilot for the Mumbai city government:

In 2020 and 2021 Mumbai developed its first Climate Action Plan with support from C40 and WRI India. The Mumbai Climate Action Plan** was launched on March 13, 2022. Emissions and removals estimated in the recently completed forests and trees in *Non-Forest Land* GHG inventory (conducted in in close partnership with the Municipal Corporation of Greater Mumbai and the Government of Maharashtra) were included in the Mumbai Climate Action Plan and the Summary for Policymakers. This demonstrates the city's efforts to adopt science-based approaches to increasing green cover and restoring forests and mangroves, including in low-income communities and vulnerable areas (Ma and Vaze 2021).

* https://canopy.itreetools.org/.

**https://mcap.mcgm.gov.in/.

5 *Establishing the data update cycle for forests and trees on* Non-Forest Land

As outlined in Chapter 4, estimating GHG emissions and removals—and thus net changes in carbon stocks—on land requires knowledge of both land use and change; information is required from at least two points in time to determine to what extent and how land use has changed over a specified inventory cycle. The "Land" sub-sector inventory cannot be based on a snapshot of land use. Data from one point in time can provide information only on land use and/or carbon stocks; a forest and tree GHG inventory requires information on land-use change and associated GHG fluxes (changes in carbon stocks over time).

The GPC requires that communities' GHG inventories cover a continuous 12-month period (GPC, Section 3.2). However, in practice, this does not mean that inventories can be updated with new data every year; inventories may be updated after several years and then annualized. This is particularly true for forests and trees. There are two main reasons that forest and tree GHG inventories may not incorporate new data annually.

1. **Data availability.** GHG inventories for forests and trees often cover multiple years because of the scarcity of data; land-use data are unlikely to be available annually or for the most recent year, unlike electricity-generation or vehicle-use data. Because the availability of land-use data is often what determines the data update cycle, the "Land" sub-sector of the GHG inventory may not occur on the same cycle or with the same regularity as inventories for other sectors (Table 9).
2. **Large disturbance events.** Even in communities in which land-use data are collected annually, GHG fluxes for the "Land" sub-sector may still be reported as an annual average over a period of several years because this can smooth out the large interannual variability in land-based emissions that may occur, particularly in areas affected by natural disturbances.

For comparability between inventory cycles and inventories for other sectors, communities shall convert total GHG fluxes from their forests and trees as calculated over a multiyear inventory into an annual average based on the number of years covered by the inventory (Step 10 of Chapters 7 and 8). The simplest way to calculate the number of years in the inventory is by subtracting the starting year from the ending year because this avoids double-counting years that abut two inventories (e.g., 2010–16 is six years and 2016–20 is four years). In this way, communities can report GHG fluxes for forests and trees annually, as required by the GPC, even if they do not have new data every year. The annualized forest and tree GHG fluxes from that inventory can then be combined with the inventories from other sectors that occurred during that time (Table 9).

Table 9 Alignment of GHG data update cycle for forests and trees with other sectors based on available data

Dataset and Area Coverage	***Forest Land*** **or Trees on** ***Non-Forest Land***	Year																			
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
GHG inventory for other sectors	N/A					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
National land-use map	*Forest Land*																				
City land-use map	*Forest Land*						1–4 (5 years)				5–8 (4 years)					9–13 (5 years)					
National tree-canopy map	Trees on *Non-Forest Land*																				
Local tree-canopy map	Trees on *Non-Forest Land*			1 (5 years)						2–9 (8 years)							10–13 (4 years)				

\# *Nonland inventory number*
Land-use data available
Tree-canopy data available
Data source not used
\# *Corresponding nonland inventories*
years *Number of years in forest/tree inventory cycle*

Notes: Tree and forest inventory data are annualized over the intervals shown.
The top row shows the GHG inventory dates for other sectors, with forest and tree data underneath (rows 2–5). In this example, two potential data sources have been identified for land use (rows 2 and 3) and two others for trees on *Non-Forest Land* (rows 4 and 5). For both land use and tree canopy, the local data (rows 3 and 5) have been chosen instead of the national data because of the preference for local data (Chapter 6). The arrows in rows 3 and 5 show which years of data have been selected for complementing the annual nonland inventories in row 1 (1, 2, 3, etc.).

6 Selecting and compiling data for the forest and tree inventory

Once a community establishes the geographical boundary identifying the spatial extent of the inventory (Step 1 of Chapters 7 and 8; also described in Chapter 4), activity data and emission or carbon gain factor data must be compiled to perform the GHG flux calculations detailed in Chapters 7 and 8. While the calculations for estimating forest- and tree-related GHG fluxes are relatively straightforward, identifying data sources may be the most complicated part of the inventory and is frequently iterative. Therefore, this chapter provides guidance to help inventory compilers understand which types of data are required to complete the inventory without being prescriptive about specific data sources or listing specific sources, which will vary by community. Table 10 provides an overview of the main types of data needed to complete the forest and trees GHG inventory.

The GPC's Chapter 5 provides an overview of inventory data sources, but forests and trees on *Non-Forest Land* have some additional considerations. There are a wide range of data sources for GHG inventories for *Forest Land* and trees on *Non-Forest Land*. Moreover, often there is no single correct answer for which data sources to use or how to use them; each community must balance different objectives, such as clarity of communication, ease and frequency of updating data used in the inventory consistently through time, level of detail, and accuracy.

Table 10 Summary of data sources needed for compiling a GHG inventory for forests and trees

	Row	Data Category	Sub-category	Type of Data Needed (Units)	Supplement Section
Forest Land	1	Activity data	Land-cover change / land-use change	Land-cover or land-use maps for multiple years (to derive land-use change matrix) (ha)	6.1
	2	Activity data	Forest disturbances	Area (and location and intensity) of *Forest Land* burned (ha)	
	3	Activity data	Forest disturbances	Area (and location and intensity) of *Forest Land* harvested (ha)	
	4	Activity data	Forest disturbances	Area (and location and intensity) of other disturbances (pest, wind, etc.) on *Forest Land* (ha)	
	5	Activity data	Forest disturbances	Annual timber harvest, fuelwood statistics (m^3 for timber or fuelwood; t for fuelwood)	
	6	Activity data	Forest subcategories	Area (and location) of different forest types, ownership classes, etc. (ha)	
	7	Emission factors	Forest emission factors	Forest carbon density in different forest types and pools (aboveground biomass, belowground biomass, deadwood, litter, soil organic carbon) (t C/ha)	6.2
	8	Carbon gain factors	Forest carbon gain factors	Mean annual increment or biomass carbon accumulation rate in different forest types and/or age classes (t C/ha/yr)	
Non-Forest Land	9	Activity data	Trees on *Non-Forest Land*	Area of tree canopy or tree census for multiple years (ha of tree canopy or # of trees)	6.3
	10	Activity data	Trees on *Non-Forest Land* subcategories	Area (and location) of different *Non-Forest Land* subcategories (ha)	
	11	Emission factors	Trees on *Non-Forest Land* emission factors	Carbon density in trees on *Non-Forest Land* (t C/ha of tree canopy or per tree)	6.4
	12	Carbon gain factors	Trees on *Non-Forest Land* carbon gain factors	Biomass carbon accumulation per area of canopy cover or per tree by trees on *Non-Forest Land* (t C/ha/yr or t C/tree/yr)	

Notes: Not all data types are needed for all communities. For example, not all communities have burned forest.
C = carbon; ha = hectares; t = metric tonnes; yr = year.

6.1 Selecting activity data for the *Forest Land* inventory

Activity data needed for calculating GHG fluxes associated with *Forest Land* include forest-related land-use changes (deforestation and afforestation or reforestation), as well as information about any forest disturbances that occurred within areas of *Forest Land remaining Forest Land* (rows 1–6 in Table 10). (Undisturbed *Forest Land remaining Forest Land* is inferred from these activity data.) There are several criteria to consider while selecting activity data for *Forest Land* and related land-use change (*Forest Land converted to Non-Forest Land*, *Non-Forest Land converted to Forest Land*) (Table 11).

Table 11 Requirements and recommendations for *Forest Land* activity data

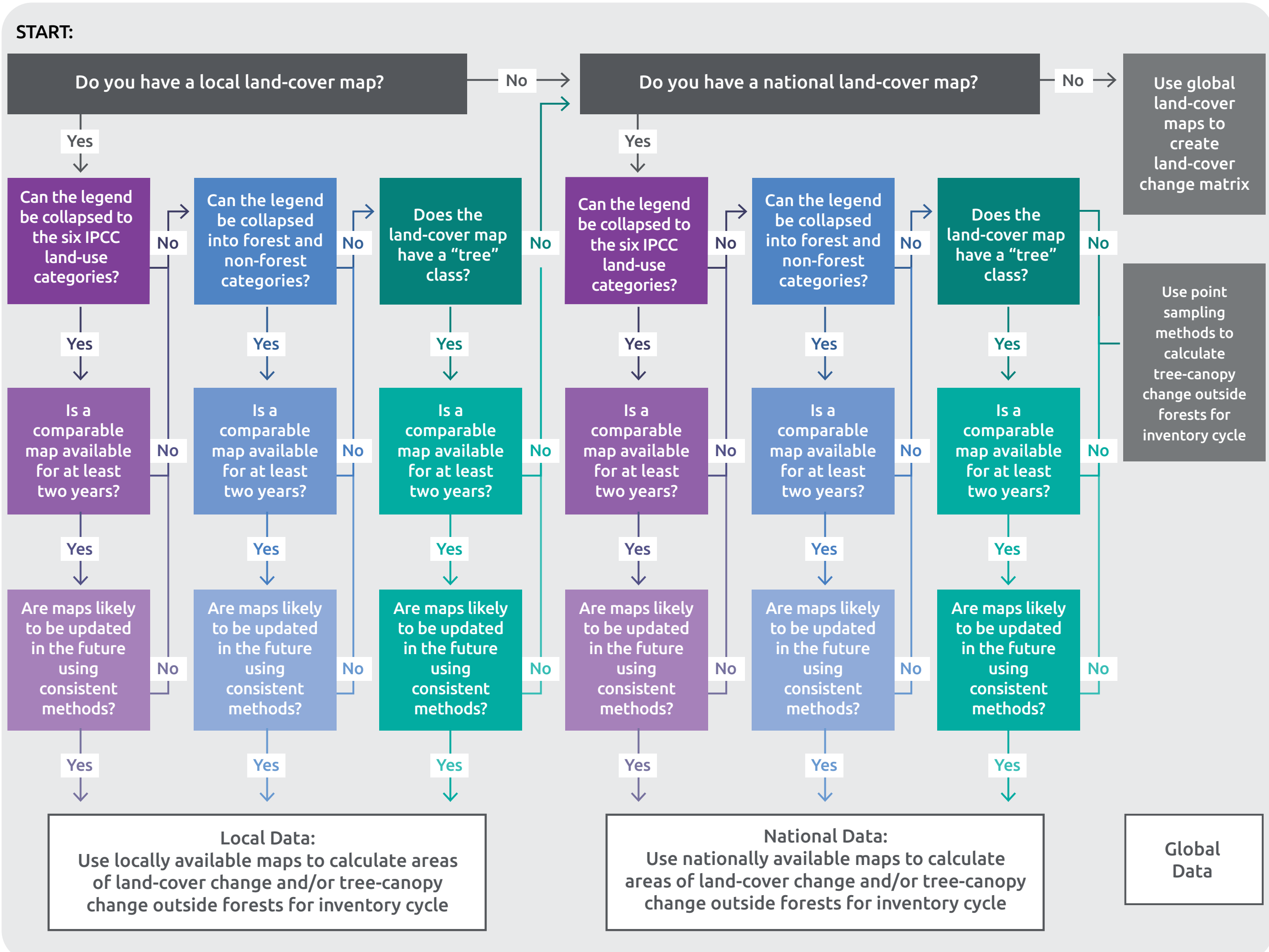
Activity Data Type	Required	Recommended
Forest Land conversion	• Data are available for multiple years, including the start and end of the inventory cycle. • The area of *Forest Land* lost, gained, and maintained during the inventory can be calculated. • Land-use classes exhaustively and exclusively cover the entire geographic boundary selected for the inventory. • Data have sufficient detail in classification and definitions to be classified into *Forest Land* and *Non-Forest Land* at a minimum, with preference for all relevant land-use classes and their transitions. Further stratification of *Forest Land* may improve the inventory but is not necessary. • Data are of sufficient spatial detail to discern changes on *Forest Land* in the inventory area. • Data are expected to be available for future inventories (for consistency across inventory cycles).	• Data represent land use, not land cover (unless land cover offers the best data available). • Data are public and have undergone independent review. • Data are the most locally applicable possible. Locally generated data are generally preferable to national or global data because they are more tailored to local conditions, may have more local support, and can be developed through community engagement.
Forest Land disturbances	• Data are available for multiple years using the same data collection methods. • Data are expected to be available for future inventories (for consistency across inventories). • The type and intensity of forest disturbance is known. • The year, location, extent, and intensity of the disturbance are known (including relevant areas and volumes of wood harvest and fuelwood extraction, if applicable).	• Data are public and have undergone independent review. • Data are the most locally applicable possible. Locally generated data are generally preferable to national or global data because they are more tailored to local conditions, may have more local support, and can be developed through community engagement.

No single data source may meet all these criteria for either kind of activity data. When selecting data, a community should evaluate strengths and weaknesses of all available activity data and document why the selected data were chosen (Case Study 3). Table 12 lists advantages and disadvantages of some broad sources for *Forest Land* activity data. Figure 5 provides a decision tree for selecting sources of activity data for both *Forest Land* and *Non-Forest Land* (trees on *Non-Forest Land* are the activity data needed for all *Non-Forest Land* uses and their transitions), particularly when considering land-use and tree-canopy map data.

Table 12 Advantages and disadvantages for sources of activity data for *Forest Land*

Option	Advantages	Disadvantages
Existing community land-use data	• Appropriate to community • Should have community buy-in • Local government is already familiar with data, which may be used in other local processes	• May be one-off, outdated, or provide incomplete coverage • May not include the necessary information for activity data, such as forest delineation
Custom land-use data	• Produced specifically for inventory and locally relevant • Potentially high accuracy • Highly reproducible • Highly customizable (e.g., have desired *Forest Land* stratification)	• Require extensive technical capacity to produce • Potentially time-consuming
National or global data	• Already available • Facilitate comparison with other communities using the same data	• May be one-off, outdated, or provide incomplete coverage • May not capture local conditions well

Figure 5 **Decision tree for selecting activity data for the GHG inventory**



Note: This decision tree does not reflect all of the considerations for selecting activity data described in this section, but the same process can be extended to include additional criteria.
Source: Authors.

Case study 3 Choosing sources of activity data from pilot in Greater Mexico City, Mexico

This case study illustrates how two sources of forest fire data were evaluated.

WRI Mexico conducted a pilot GHG inventory for the Metropolitan Area of the Valley of Mexico, which includes Mexico City, part of Mexico State, and part of Hidalgo State in Mexico, for the years 2007–14. Historical fire monitoring has shown that *Forest Land* within the inventory area has experienced extensive fires, with concomitant non-CO_2 GHG emissions. The importance of including emissions from forest fires was validated in discussions with the Climate Action and Air Quality Directorates of the Environmental Secretariat of Mexico City (SEDEMA), the government agency responsible for monitoring land-use change and associated impacts.

Two data sources for forest fire occurrence were evaluated for this inventory: (1) national data on forest areas burned from the National Forest Commission (CONAFOR), and (2) global burned area data from the MODIS sensor of the Terra satellite. Although the CONAFOR fire data are nationally accepted, they had some key disadvantages for the purposes of this inventory: (1) only half of the fires recorded by CONAFOR for the years included in the inventory had geographic coordinates, and (2) it was not clear if CONAFOR would continue to collect fire data (which would result in more updated inventories using different fire data). Ultimately, the MODIS burned area data were used in the pilot inventory because they were spatially explicit and expected to continue to be collected. Emission factors for forest fires were obtained from Mexico's National Forest Reference Emissions Level (CONAFOR 2015) and were combined with the burned area activity data.

Relevance of the pilot for the Mexico City government:

Since completing the pilot inventory for Mexico City, the results have been presented to SEDEMA, which is exploring the options to include the results in municipalities' climate plans.

Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

6.2 Selecting emission and carbon gain factors for the *Forest Land* inventory

Applicable ecosystem carbon pools (aboveground biomass, belowground biomass, deadwood, litter, and soil carbon) are apportioned into two factors:

- Emissions (t C/ha): for *Forest Land converted to Non-Forest Land*, and for *Forest Land remaining Forest Land* that has undergone a substantial disturbance.
- Carbon gain (t C/ha/yr): for *Non-Forest Land converted to Forest Land*, and for undisturbed *Forest Land* (i.e., forest condition has not been modified during the inventory data update cycle).

Emission and carbon gain factors for *Forest Land* should be comprehensive; that is, they should represent the changes in carbon stocks that occur for any of the five ecosystem carbon pools which are significantly affected (rows 7–8 in Table 10). However, the availability of data for calculating emission and carbon gain factors in a community context is likely to be different for different land-use categories and carbon pools. In national GHG inventories, it is common practice to ignore small changes in selected carbon pools (i.e., 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. Communities may take the same approach. Communities shall provide transparent documentation on which carbon pools are included and excluded in the estimation of emission and carbon gain factors.

Emission and carbon gain factors for *Forest Land* can be developed using information collected by local, state, provincial, or national governments; universities; or nongovernmental organizations, or by applying default factors developed and published in the IPCC Guidelines for national GHG inventory reporting (Box 9). If a community has local data about carbon associated with *Forest Land*, they, rather than more generic estimates, should be used. Table 13 lists advantages and disadvantages of some different sources for emission and carbon gain factors.

- Emission factors are often derived from field measurements of tree carbon density, or sometimes from remote-sensing approaches with field validation. Communities with local data on *Forest Land* carbon stocks can use these as the basis for emission factors. If predisturbance estimates of biomass and soil carbon stocks are not locally available for *Forest Land*, regional averages for aboveground biomass and other carbon pools can be used.
- Carbon gain factors can be derived from repeated measurements of forest carbon in plots over multiple years, usually from forest inventories. Because forest inventories are resource-intensive and require large samples to obtain low uncertainty, communities may not have their own forest inventory data for creating carbon gain factors, in which case they should investigate national data or IPCC defaults.

Depending on available data, separate emission and carbon gain factors may be developed for different forest types, disturbance types, forest age classes, and so on. Further guidance on calculating emission and carbon gain factors for *Forest Land* can be found in Chapter 7, Step 5.

Box 9 The IPCC tier concept

The IPCC classifies methodological approaches for estimating land-based GHG fluxes into three different “tiers,” according to the quantity of information required and the degree of analytical complexity.

Tier 1 employs the method described in the IPCC National GHG Inventory Guidelines using country-specific activity data and the default emission or removal factors and other parameters provided by the IPCC. There are simplifying assumptions about some carbon pools. Tier 1 methodologies may be combined with spatially explicit activity data estimated from remote sensing.

Tier 2 generally uses the same methodological approach as Tier 1 but applies emission or carbon gain factors and other parameters specific to the country (or community, in this case). Community-specific emission or carbon gain factors and parameters are those more appropriate to the forests, climatic regions, and land-use systems in that community. More highly stratified activity data (e.g., activity data for different forest types) may be needed in Tier 2 to correspond with community-specific emission or carbon gain factors.

At **Tier 3**, higher-order methods include more complex models and are generally more flexible than Tier 1 or 2 systems as they can more easily accommodate a wide range of different types and sources of data. Tier 3 systems may include a closer link between biomass and soil carbon dynamics as compared to Tiers 1 and 2.

Progressing from Tier 1 to Tier 3 generally represents a reduction in the uncertainty of GHG estimates, though at a cost of increasing data and analysis complexity. The selection of an appropriate tier depends on a community’s circumstances, including operational budgets, infrastructure and capacity, and what the outputs will be used for and why. Experience of developing national GHG inventories suggests that even a system that is Tier 3 overall will use Tier 1 or Tier 2 emission or removal factors for some components of the inventory. For both national and community-scale GHG inventory reporting, a combination of tiers, most often Tier 1 and Tier 2, is most likely to be used. Communities should strive to progressively use more higher-tier data in subsequent inventories.

Notes: GHG = greenhouse gas; IPCC = Intergovernmental Panel on Climate Change.
Source: Adapted from GFOI (2016).

Table 13 Advantages and disadvantages of data sources for emission and carbon gain factors for *Forest Land*

Option	Advantages	Disadvantages
IPCC defaults from National GHG Inventory Guidelines (Tier 1)	• Globally available • Well documented and reviewed • Cover all carbon pools	• Very general factors, one per ecological zone • Not necessarily locally applicable
Forest carbon density maps (emission factors only)	• Wall-to-wall coverage is conducive to stratification and summarization by different areas (subcategories) • Allow emission factors to be co-located with disturbance and land-use data	• Require additional GIS expertise • High uncertainty at pixel scale • Usually include just aboveground biomass carbon; need to calculate other carbon pools • May be out-of-date or too recent; that is, recent maps may estimate carbon density after the forest disturbance has already occurred, rather than predisturbance (which is what is needed to pair with relevant activity data)
National or local reports (e.g., National Communications to UNFCCC, REDD+ reports, Forest Reference Emission-Level reports, National Forest Inventories, research from local universities)	• Relevant to local forest types • May have support of local stakeholders • May have different factors for different local forest types • May cover forest and nonforest areas	• May not be statistically representative for local areas • Expensive and time-consuming to obtain if they do not currently exist • Local plot methods may not be consistent with national methods • May be out-of-date or measured infrequently, data updates may not be planned • May not cover all carbon pools

Notes: GIS = geographic information system; IPCC = Intergovernmental Panel on Climate Change; REDD+ = Reducing Emissions from Deforestation and forest Degradation, plus the sustainable management of forests, and the conservation and enhancement of forest stocks; UNFCCC = UN Framework Convention on Climate Change.

6.3 Selecting activity data for the trees on *Non-Forest Land* inventory

For *Forest Land*, the basis of the GHG inventory calculations is the areas of *Forest Land*, *Forest Land* area change, and forest disturbances, potentially stratified by different forest types. For *Non-Forest Land*, the basis of the GHG inventory calculations is usually estimates of the area of tree-canopy cover and canopy-cover change occurring on *Non-Forest Land* during the inventory cycle (rows 9–10 in Table 10). As noted in Chapter 1, this supplement covers only tree biomass changes in *Non-Forest Land*; guidance on estimating soil or other vegetation GHG fluxes on these lands is not covered (Table 1).

There are two broad kinds of activity data for trees on *Non-Forest Land*, depending on which data are available:

1. **Inventories of individual trees**: Censuses of individual trees can be disaggregated into species or broad species classes, either through field data collection or remotely using very high-resolution aerial or satellite imagery. Municipal tree databases may comprehensively include information on tree species, diameter at breast height, tree height, canopy area, or information about tree health and mortality. However, to be useful for the trees on *Non-Forest Land* GHG inventory, these tree surveys must be repeated with the same methods in multiple, inventory-relevant years over

the entire inventory area to calculate change in canopy for trees on *Non-Forest Land* (just like for *Forest Land*).

2. **The area of tree crown or canopy cover:** This could be wall-to-wall maps of tree cover and change derived from high resolution imagery such as aerial photographs, light detection and ranging imagery, or satellite imagery. Alternatively, tree canopy and change may be estimated using a sample-based approach, in which human interpreters look at randomly assigned points within high resolution imagery at multiple points in time and label them as tree or nontree, after which summary statistics are calculated for the average area of tree canopy and canopy change within different *Non-Forest Land* subcategories during the inventory cycle (Case Study 4). This kind of activity data may be more likely for communities because repeated, complete tree censuses are uncommon.

Some communities may have a mixture of these two kinds of data or only one of them for part of the inventory area. In such cases, the community needs to decide how to combine the data sources, which one to use, and how to fill gaps. Communities may have inventories of government-managed trees, but such inventories do not include privately owned trees and are therefore not complete enough to use for a community-wide inventory.

There are several criteria to consider when selecting activity data for trees on *Non-Forest Land* (Table 14). No single data source may meet all these criteria. When selecting data, a community should evaluate strengths and weaknesses of all available activity data and document why the selected data were chosen. Table 15 lists advantages and disadvantages of some different sources for trees on *Non-Forest Land* activity data.

Table 14 Requirements and recommendations for trees on *Non-Forest Land* activity data

Activity Data Type	Required	Recommended
Loss, gain, and maintenance of trees on *Non-Forest Land* (either tree counts or canopy area)	• Data are available for multiple years, including the start and end of the inventory cycle. • The canopy area or number of trees on *Non-Forest Land* that are lost, gained, and maintained during the inventory can be calculated. • Data are expected to be available for future inventories (for consistency across inventory cycles).	• Communities use the same activity data for the entire inventory area, rather than different sources for different areas, such as a tree survey for the city center and aerial imagery for the rest of the community. Using the same activity data for the entire inventory area simplifies calculations and facilitates comparison across the entire inventory area. • Data are public and have undergone independent review. • Data are the most locally applicable possible. Locally generated data are generally preferable to national or global data because they are more tailored to local conditions, may have more local support, and can be developed through community engagement. For example, local organizations can participate in estimating changes in tree canopy with i-Tree Canopy (USDA Forest Service 2021).

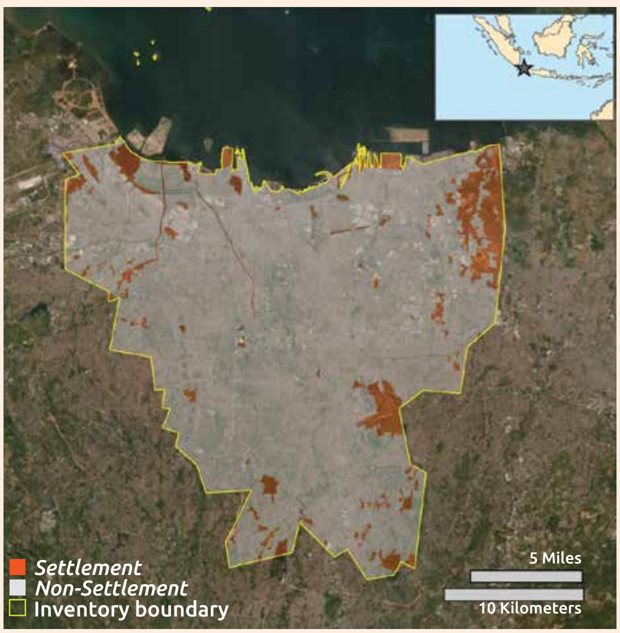
Table 15 Advantages and disadvantages for sources of activity data for trees on *Non-Forest Land* (tree canopy lost, gained, and maintained)

Option	Advantages	Disadvantages
Existing community tree inventory (canopy count or area)	• Local data are appropriate to community • Should have community buy-in • Local government is already familiar with it	• May be one-off, outdated, or provide incomplete coverage (e.g., only government property) • May not include the necessary information for activity data
Custom canopy area census (such as sample-based approach for photointerpretation)	• Produced specifically for inventory and locally relevant • Potentially high accuracy • Highly reproducible • Highly customizable	• Requires extensive technical capacity to produce • Potentially time-consuming
National data	• Already available • Facilitate comparison with other communities if they are using the same data	• May be one-off, outdated, or provide incomplete coverage • May not capture local conditions well

Case study 4 Deciding between two methods for calculating activity data for trees on *Non-Forest Land* from pilot in Jakarta, Indonesia

This case study illustrates how two sources of activity data for trees on Non-Forest Land *were evaluated.*

Jakarta is highly urbanized, with the only *Forest Land* being mangroves and dry forest on small islands. In the rest of the city, patches of *Non-Settlements* are interspersed with *Settlements*, and thus Jakarta's inventory "Land" sub-sector fluxes were dominated by trees on *Non-Forest Land* in this inventory. WRI Indonesia stratified the *Non-Forest Land* inventory into *Settlement* and *Non-Settlement* areas because this supports the design and monitoring of specific interventions, policies, and results of changes in trees on *Non-Forest Land*.



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

For this greenhouse gas (GHG) inventory spanning two cycles (2011–18 and 2018–20), WRI Indonesia staff estimated GHG fluxes from trees on *Non-Forest Land* in Jakarta using two methods: (1) tree cover using a map generated by a machine learning model using Collect Earth Online (FAO 2020), Landsat imagery, Sentinel imagery, and Google Earth Engine, and (2) tree cover using a statistical (nonspatially explicit) approach based on sample results collected using i-Tree Canopy (USDA Forest Service 2021). Collect Earth Online is a free tool for photo-interpretation sampling of remote-sensing products, the results of which can then be easily incorporated into machine learning models to make wall-to-wall land-cover maps. i-Tree Canopy allows users to interpret free satellite imagery at randomly placed points, thereby estimating tree canopy (including in *Non-Forest Land*) and change in that canopy over time. Results from the two approaches differed, with map output from the machine learning model indicating a decrease in tree-canopy cover and the i-Tree-canopy sample-based results indicating an increase in tree-canopy cover over the inventory.

Detailed comparisons and spot checks of the map output against high-resolution imagery revealed substantial errors in the machine learning model-based approach. Therefore, despite the appeal of using a machine learning model that produced spatially explicit outputs, the inventory team decided not to use this automated approach for activity data for trees on *Non-Forest Land*, opting instead to use the statistical estimate from i-Tree Canopy because it was more accurate. Greenhouse gas fluxes for trees in *Settlement* and *Non-Settlement* areas were estimated using different emission and carbon gain factors because of known differences in the vegetation found in the two subcategories.

Relevance of the pilot for the Jakarta government:

WRI Indonesia has been working with the Jakarta government for more than three years under the auspices of the Cities4Forests initiative, of which Jakarta is a member. Cities4Forests support resulted in the issuance in 2021 of two new gubernatorial regulations on tree management and protection, and on the provisioning and use of parks. The governor of Jakarta has committed to reduce GHG emissions by 50 percent by 2030 and to achieve a net zero target by 2050, and enacted a low-carbon development plan to achieve these targets. This forest and tree GHG inventory shows how these results can contribute to achieving these targets. In general, this pilot inventory represents another example of concrete technical assistance that the Jakarta government can leverage to create a more resilient, green, and sustainable city for all of its residents.

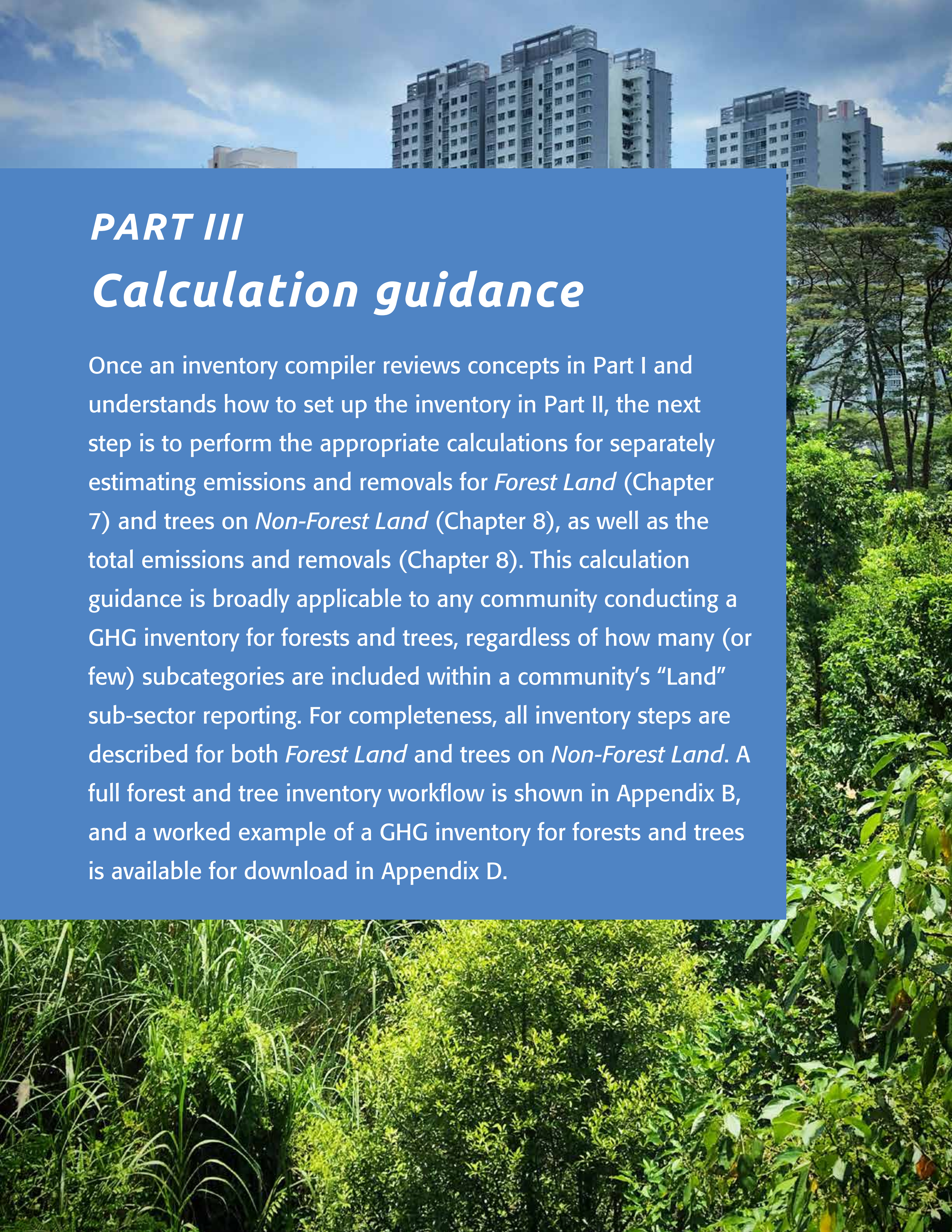
6.4 Selecting emission and carbon gain factors for the trees on *Non-Forest Land* inventory

Activity data (e.g., tree-canopy cover and change) can be generated specifically for a community's *Non-Forest Land* (Table 13), but emission and carbon gain factors are not likely to be estimated as easily. This is because the information needed to develop emission and carbon gain factors for trees on *Non-Forest Land*, like carbon densities or annual carbon increments, are rarely measured outside of *Forest Land*. Therefore, the data available to estimate locally calibrated emission and carbon gain factors for trees on *Non-Forest Land* may be extremely limited for most communities. Communities may need to use global default carbon gain factors from IPCC national greenhouse gas inventory guidelines (IPCC 2019b) if local or even national data are not available. The difficulty in finding locally relevant data for trees on *Non-Forest Land* can indicate to communities one avenue for improving future "Land" sub-sector inventories. The same kinds of data sources for emission and carbon gain factors can be searched for trees on *Non-Forest Land* and for *Forest Land* (Table 13).

There are two general kinds of data for developing emission and carbon gain factors associated with changes in trees on *Non-Forest Land* (rows 11–12 in Table 10). They correspond to the two approaches to estimating activity data for trees on *Non-Forest Land*: activity data by individual tree and by canopy area:

1. When individual trees from a tree census are used for activity data: Models calibrated to the sampling area are applied that convert data on tree species, diameter at breast height, tree height, dieback, crown light exposure, and distance and direction to buildings into estimates of storage (for emission factors) and net annual carbon gain, which accounts for tree mortality or death (for carbon gain factors), including sampling errors.
2. When area of tree canopy outside forests in *Non-Forest Land* is used for activity data:
    a. Carbon gain factors (average rates of carbon sequestration per hectare of tree canopy per year): Estimated from inventories of trees outside forests from representative areas. If local data are not available for non-*Settlement* land uses, this supplement recommends that communities apply emission and carbon gain factors developed for *Settlements* to other *Non-Forest Land* uses, as it is reasonable to assume that trees on *Non-Forest Land* have biomass and growth characteristics more similar to urban trees in similar geographic areas than to trees in nearby forests, which have much higher stocking density. Urban data may be more readily available than data for other land uses. If nearby urban tree carbon gain factors are not available, the best option is to use data from nearby forests. When nothing else is available, the IPCC default carbon gain factor for urban trees may be used (2.8 t C/ha tree canopy/year for nonboreal regions, 2.1 t C/ha tree canopy/year for boreal regions) (IPCC 2019b, vol. 4, chap. 8, p. 8.5).
    b. Emission factors: If no data on carbon density for trees on *Non-Forest Land* are available, a default of 80 percent of forest carbon density in the most relevant forest type can be used (IPCC 2019b). For example, if the average forest biomass carbon density is 100 t C/ha, the biomass carbon density assumed for trees on *Non-Forest Land* would be 80 t C/ha. The same default would apply if the inventory is conducted using numbers of trees instead of canopy area.

Further guidance on calculating emission and carbon gain factors for trees on *Non-Forest Land* can be found in Chapter 8, Step 5.



PART III
Calculation guidance

Once an inventory compiler reviews concepts in Part I and understands how to set up the inventory in Part II, the next step is to perform the appropriate calculations for separately estimating emissions and removals for *Forest Land* (Chapter 7) and trees on *Non-Forest Land* (Chapter 8), as well as the total emissions and removals (Chapter 8). This calculation guidance is broadly applicable to any community conducting a GHG inventory for forests and trees, regardless of how many (or few) subcategories are included within a community's “Land” sub-sector reporting. For completeness, all inventory steps are described for both *Forest Land* and trees on *Non-Forest Land*. A full forest and tree inventory workflow is shown in Appendix B, and a worked example of a GHG inventory for forests and trees is available for download in Appendix D.

7 *Calculating GHG fluxes for* Forest Land

This chapter provides guidance on calculating GHG fluxes occurring within the three broad *Forest Land*–related categories of the land-use change matrix: *Forest Land remaining Forest Land*, *Forest Land converted to Non-Forest Land* (i.e., deforestation), and *Non-Forest Land converted to Forest Land* (i.e., afforestation or reforestation). They correspond to the cells across the left column and top row of the 6x6 category land-use change matrix (Table 5). Inventories that include the "Land" sub-sector shall include these three broad categories. Communities shall also determine whether there were substantial changes in condition within *Forest Land remaining Forest Land* that need to be included in the inventory, such as forest disturbances (fires, disease outbreaks, etc.) or forest management activities (harvesting, thinning, etc.) which would be associated with emissions. GHG fluxes from tree biomass in the rest of the land-use change matrix are covered in Chapter 8. A link to a downloadable spreadsheet with a worked sample inventory can be found in Appendix D.

As shown in Figure 6, there are three stages to the *Forest Land* inventory, each with multiple steps. (Stage 4 occurs after the GHG inventories for both *Forest Land* and *Non-Forest Land* have been completed.) Although the steps are presented in the order below, they may be completed iteratively, particularly the data selection steps in Stage 1. Often, as data are compiled and preliminary calculations are completed, earlier steps are revisited. Much of Stage 1 is covered in Chapters 4, 5, and 6, but it is summarized in this chapter so that all steps related to calculating GHG fluxes for *Forest Land* are contained in a single chapter.

Step 1: Establish the geographical boundary of the inventory area (see Chapter 4)

Stage 1: Explore and select data sources (the "data selection cycle")

Step 2: Select sources of activity data for land-use change and disturbance for *Forest Land* (Chapter 6)

Step 3: Select the inventory cycle for *Forest Land* (Chapter 5)

Step 4: Select subcategories for *Forest Land* (Chapter 4)

Step 5: Select corresponding emission and carbon gain factors for *Forest Land* (Chapter 6)

Stage 2: Prepare and assign activity data, emission factors, and carbon gain factors

Step 6a: Calculate activity data for *Forest Land* and its transitions (*Forest Land converted to Non-Forest Land, Non-Forest Land converted to Forest Land,* and *Forest Land remaining Forest Land*)

Step 6b: Reassign ("correct") *Forest Land* activity data, if needed

Step 7: Develop *Forest Land* emission and carbon gain factors and match them with activity data for *Forest Land*

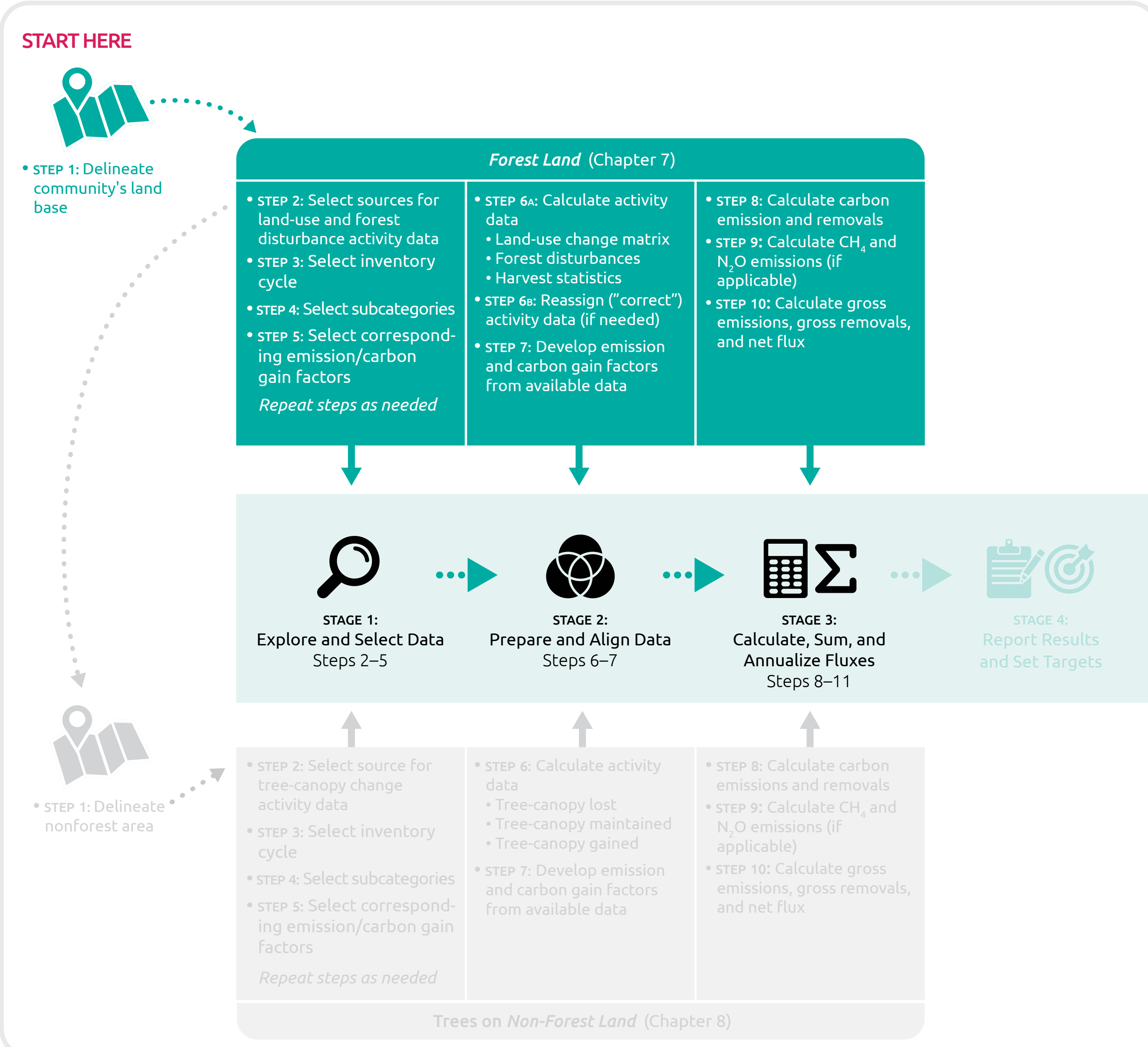
Stage 3: Calculate, sum, and annualize GHG fluxes

Step 8 Calculate carbon emissions and removals for *Forest Land*

Step 9: Calculate non-CO_2 emissions for *Forest Land* (if applicable)

Step 10: Calculate gross emissions, gross removals, and net *Forest Land* GHG flux during the inventory and annualize the results into t CO_2e/yr

Figure 6 **Steps for completing the *Forest Land* GHG inventory**



Note: CH_4 = methane; N_2O = nitrous oxide.
Four overall stages are shown (middle horizontal box). A community's lands are divided into *Forest Land* (top) and *Non-Forest Land* (bottom). Top and bottom boxes show the steps an inventory compiler must carry out for each land type to complete three of the four stages of the overall process.
Source: Authors.

Step 1: Establish the geographical boundary of the inventory area

This is a convenient place to start the inventory process because it is often predetermined and not affected by other steps; hence, it is shown outside the data selection cycle. Selecting the inventory area (i.e., delineating the community's land base) was addressed in Section 4.1.

Step 2: Select sources of activity data for land-use change and disturbances for *Forest Land*

All inventories that include the "Land" sub-sector of AFOLU shall include all forest-related land-use transitions (i.e., deforestation and afforestation or reforestation) and *Forest Land remaining Forest Land*. Communities shall also determine whether there were substantial changes in condition within *Forest Land remaining Forest Land* that need to be included in the inventory, such as forest disturbances (fires, disease outbreaks, etc.) or forest management activities (harvesting, thinning, etc.) which would be associated with emissions, in addition to CO_2 removals by undisturbed *Forest Land remaining Forest Land*. Which data source to use can be determined through geospatial analysis, discussion with community organizations, consultation with other government departments or private forest management companies within the community, and so on. Selecting activity data was addressed in Section 6.1 (Table 12, Figure 5).

Step 3: Select the inventory cycle for *Forest Land*

Land-use change data and the inventory cycle particularly depend on each other (Table 9). For many communities, there may be only one option for land-use change data, which will then dictate the years covered by the inventory. This supplement recommends that communities survey which land-use change data are available before selecting an inventory cycle. Choosing an inventory cycle may be further constrained by trying to match the "Land" sub-sector's years with the other sectors' inventory. For communities with multiple sources of land-use data, there may be more options for selecting inventory cycles and additional iteration between land-use data selection, inventory cycle selection, and matching with other sectors' inventory dates. The reason for selecting the inventory years for *Forest Land* included in an inventory cycle shall be documented, including, if applicable, the reasons why the monitoring period for *Forest Land* differs from that for trees on *Non-Forest Land*. Selecting the inventory cycle was addressed in Chapter 5.

Step 4: Select subcategories for *Forest Land*

The simplest way to conduct and present a *Forest Land* GHG inventory is by keeping all *Forest Land* as a single category (Table 6). However, this may not always be the most accurate or useful way to conduct or share the inventory. In some situations, stratifying *Forest Land* (public vs. private, primary vs. secondary forest, etc.) may improve analysis and/or reporting. For example, stratifying *Forest Land* to correspond with emission and carbon gain factors for specific forest types can improve the accuracy of the inventory (Table 7). In such cases, maps of available forest subcategories need corresponding emission and carbon gain factors. Stratification can be done by intersecting the *Forest Land* map with geospatial boundaries of the desired subcategories.

Stratification was addressed in Section 4.4. There is no single correct way to stratify *Forest Land* for a community; each community's objectives and available data will determine the appropriate approach.

Step 5: Select corresponding emission and carbon gain factors for *Forest Land*

This step will depend on the activity data and subcategories chosen. Every forest subcategory shall have a corresponding emission and/or carbon gain factor, although the factors do not need to be unique to every *Forest Land* subcategory (i.e., subcategories can share the same emission and/or carbon gain factors). Selecting emission and carbon gain factors was addressed in Section 6.2 (Table 13).

Step 6a: Calculate activity data for *Forest Land* and its land use transitions

Once the inventory area, inventory cycle, and data sources have been selected (Stage 1), activity data and emission or carbon gain factors can be prepared and aligned (Stage 2) so that they can be combined in GHG flux calculations (Stage 3).

At a minimum, activity data needed for calculating *Forest Land* GHG fluxes include the following categories, which should reflect total areas (in hectares) over the inventory cycle (not annualized). All of these activity data can be stratified according to subcategories chosen in Step 4. A GIS analyst is likely to be needed to calculate relevant areas for the community from spatial data (i.e., land-use change maps, disturbance areas).

Area of *Forest Land* that changed to a different land use during the inventory (*Forest Land converted to Non-Forest Land*). The activity data are estimated as the total area of *Forest Land* lost during the inventory. This land is represented as the pink boxes on the top row of the land-use change matrix in Table 5 and can be calculated for each conversion category separately (in the case of a 6x6 land-use change matrix or a matrix in which *Forest Land* is stratified). Alternatively, a simplified approach may be used to estimate the total area of deforestation that does not distinguish between the subsequent land use (in the case of a 2x2 land-use change matrix, found in Table 6). Which approach is used is determined by the selected subcategories.

Area of *Non-Forest Land* that changed to a *Forest Land* use during the inventory (*Non-Forest Land converted to Forest Land*). The activity data are estimated as the total forest area gained during the inventory. This land is represented as the light green boxes in the left column of the land-use change matrix (Table 5) and can be calculated for each *Non-Forest Land* category separately (in the case of a 6x6 land-use change matrix, i.e., area of *Cropland converted to Forest Land*, *Grassland converted to Forest Land*, etc.). Alternatively, a simplified approach may be used to estimate the total area of *Non-Forest Land converted to Forest Land* that does not distinguish between the previous land use (in the case of a 2x2 land-use change matrix, found in Table 6). Which approach is used is determined by the selected subcategories.

Area of *Forest Land* that did not change use during the inventory (*Forest Land remaining Forest Land*). The simplified gain-loss method applied in this supplement for calculating GHG fluxes recognizes two general cases of *Forest Land remaining Forest Land*: disturbed and undisturbed. Therefore, activity data for the total area of *Forest Land remaining Forest Land* need to be split into area of disturbed forest and area of undisturbed forest. The former includes areas that were subject to tree harvest for commercial or other purposes, as well as forest areas undergoing any other type of disturbance that occurred during the inventory cycle but that are still considered *Forest Land remaining Forest Land* from a land-use perspective. The latter (undisturbed *Forest Land*) includes all other *Forest Land remaining Forest Land* outside areas of disturbance. These areas are collectively represented as the top left dark green box of the land-use change matrix in Table 5. This can also be stratified (Table 7).

Area of *Forest Land* disturbed during the inventory. For disturbed forests, activity data are the areas of disturbance that occurred within each *Forest Land remaining Forest Land* subcategory during the inventory. Depending on available data, disturbances may be split further into different types and severities of disturbance, since these can result in different levels of emissions (and subsequent removals). If disturbances or management activities occurred but no spatial data are available to identify where, the community must make some assumptions about the forest types in which those events most likely occurred to include them in the inventory if different emission factors are developed for different forest types. For example, if a community knows that a certain amount of forest was harvested during the inventory but has no information regarding the location, the community will need to decide how to apportion that area among different *Forest Land remaining Forest Land* subcategories (if applicable). In addition, if forest management activities occurred within the community during the inventory, data on harvest volumes for timber or fuelwood shall be used to estimate emissions for these types of disturbances, since not all harvest activity may be detected as a forest disturbance in satellite-based land-cover change-monitoring approaches.

Area of undisturbed *Forest Land* during the inventory. The area of undisturbed forest is calculated as the difference between total area of *Forest Land remaining Forest Land* and the sum of all disturbed *Forest Land*. For some communities, there may be no disturbances detected in *Forest Land remaining Forest Land* and this entire category will be undisturbed.

If spatial datasets are used to map areas and locations of forest disturbances, it may be necessary to reconcile areas where more than one result is possible for the same area due to overlapping criteria. For example, during an inventory cycle, an area within the community may appear in the land-use change matrix as *Forest Land converted to Grassland*, while also being classified in one or several of the forest disturbance maps as an area of disturbed *Forest Land remaining Forest Land*. In these cases, one dataset may be assigned to take priority over another. One option is for the land-use change matrix to take highest priority, so that areas of land-use change are calculated first. Then, areas of disturbance can be calculated only for areas classified in the land-use change matrix as *Forest Land remaining Forest Land*. Within these areas, it is simplest to assign only one disturbance type per disturbed forest area during a given inventory cycle, even though it is technically possible for mapped areas of different disturbances to overlap during the same cycle (e.g., harvest and fire). In the case of multiple disturbances, a hierarchy should be created with different disturbances assigned in decreasing order of priority, which can be set based on local knowledge, the quality of the data sources used, and/or the severity of the disturbance and its likely impact on GHG fluxes.

Step 6b: Reassign ("correct") *Forest Land* activity data, if needed

When land-cover maps are used by a community as the basis for calculating a land-use change matrix, temporary changes in land cover can sometimes be conflated with changes in land use (Box 8), resulting in incorrectly calculated and reported fluxes. In such cases, communities may need to "correct" their preliminary activity data for *Forest Land* before calculating fluxes to report activity data in the right land-use category.

Corrections are particularly relevant for *Forest Land* categories because misassignment generally occurs during a temporary loss of tree cover within *Forest Land* that has been classified as a permanent change in the land-use change matrix. An example of this occurs following severe natural disturbances or harvesting, where a large proportion of the trees die or are cut, resulting in the disturbed areas being classified as *Forest Land converted to Grassland* in the next land-cover map although the land use remains *Forest Land*. The land cover may gradually revert to forest as the trees regenerate, and so the land remains in a forest use, while the land-cover change map indicates loss of forest cover.

Three broad levels of activity data corrections are possible:

1. **No correction:** If careful analysis determines that there is no or very little land-cover change (in the case of *Forest Land remaining Forest Land*), or that the land-cover change is truly conversion to a new land use (in the case of *Forest Land converted to Non-Forest Land*), then no correction is needed.
2. **Correcting whole categories:** If all conversion from *Forest Land* to a specific *Non-Forest Land* use (e.g., *Grassland*) is deemed by the community to be temporary, then all the activity data of *Forest Land converted to Non-Forest Land* in that cell of the land-use change matrix may be reassigned to disturbed *Forest Land* reported in the *Forest Land remaining Forest Land* category. Likewise, if there are areas classified as *Non-Forest Land converted to Forest Land* that represent the return to forest cover following temporary conversion to something else, then the activity data within that *Non-Forest Land to Forest Land* category can be reassigned to *Forest Land remaining Forest Land* (Box 10).
3. **Correcting partial categories:** A community may determine that only some of the reported activity data from one land-use change category should be reassigned to another. This requires estimating the proportion of the land-use change that is considered permanent, which can be determined by visually inspecting high-resolution satellite imagery or aerial photos of the disturbed areas from later dates or, if the change occurred recently, visiting the site in person. For example, half of the reported conversion of *Forest Land converted to Grassland* may be found to be permanent and half temporary destocking in *Forest Land remaining Forest Land*.

When determining if a correction is needed, it is important to understand the context in which a change in land cover takes place. Knowledge of the type, severity, and frequency of disturbance and the purposes for which the land is managed will help a community determine if the land-cover change is temporary or permanent. For example, if timber harvesting takes place within a managed forest concession, it is highly likely that the change in land cover from *Forest Land to Grassland* is temporary. In contrast, if trees are removed in a community area that has an expanding urban population or an increasing use of land to support livestock or crops, it is much more likely that the change in land cover represents a change in land use.

Another sign of land-cover change being incorrectly reported as land-use change is if the land-use change matrix shows substantial opposing land-cover changes happening in both directions within the same inventory; for example, significant areas are changing cover from *Forest Land converted to Grassland* during the same time as areas are changing from *Grassland converted to Forest Land* (Box 10). This may indicate a cyclical pattern of harvest or disturbance followed by recovery of the forest.

Another source of misassigned activity data can come from *Non-Forest Land converted to Forest Land*. This is partially because there are multiple ways this can occur. Regeneration, afforestation, and reforestation have many definitions; each community should use locally relevant definitions.

- **Regeneration** is associated with the management of *Forest Land remaining Forest Land*.
- **Afforestation** is generally used to define instances of land-use change from *Non-Forest Land to Forest Land* where the area has not been classified as *Forest Land* for an extended period or was never classified as *Forest Land* and is planted, seeded, or allowed to naturally regenerate to establish *Forest Land*.
- **Reforestation** involves land that was originally *Forest Land*, then converted to *Non-Forest Land*, and then changed back from *Non-Forest Land* to *Forest Land* after having been deforested for an extended period.

To simplify the estimation process and because many communities lack historical land-use data, afforestation and reforestation should be considered as land-use changes 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 regenerate naturally. These areas should be considered *Forest Land remaining Forest Land* rather than counted as a land-use change.

All investigation into and decisions about corrections applied to the land-use change matrix shall be documented and justified.

Box 10 Example "correction" to land-use change matrix

In this example of "uncorrected" activity data, 300 hectares (ha) of land was miscategorized as *Forest Land converted to Grassland*. After closer inspection of the data, this was deemed to represent a forest harvest rather than land-use change. Therefore, these 300 hectares were moved into the disturbed *Forest Land remaining Forest Land* category, increasing the total area of disturbed *Forest Land remaining Forest Land* during the inventory from 500 ha (uncorrected) to 800 ha (corrected). Similarly, the 400 ha of *Grassland converted to Forest Land* was deemed to be recent regeneration of previously harvested forest areas rather than land-use change, so another 400 ha were moved into disturbed *Forest Land remaining Forest Land*, increasing it to 1,200 ha (corrected). This resulted in a total of 2,200 ha of *Forest Land remaining Forest Land* (corrected) instead of 1,500 ha (uncorrected).

UNCORRECTED REPORT

Land use at start of inventory period	Land use at the end of inventory period			
Area (ha)	*Forest Land*	*Grassland*	*Other*	
Forest Land	1,500 *(1,000 undisturbed, 500 disturbed)*	300	200
Grassland	400	N/A	N/A
Other	0	N/A	N/A

Grassland
↓
Forest Land Disturbed
Area Removed: 400 ha

Forest Land Disturbed
↓
Grassland
Area Removed: 300 ha

CORRECTED REPORT

Land use at start of inventory period	Land use at the end of inventory period			
Area (ha)	*Forest Land*	*Grassland*	*Other*	
Forest Land	2,200 *(1,000 undisturbed, 1,200 disturbed)*	0	200
Grassland	0	N/A	N/A
Other	0	N/A	N/A

Step 7: Develop emission and carbon gain factors and match them with activity data for *Forest Land*

Emission and carbon gain factors are highly dependent on the presence, nature, and severity of the change occurring, in the case of emission factors, and on the age, type, and climate conditions of forest growing, in the case of carbon gain factors. As with activity data, the degree of accuracy and precision that can be achieved in the estimation of forest-related GHG fluxes will depend on the local specificity of the data available from which to develop emission and carbon gain factors for different areas. Chapter 6 included some general considerations for selecting data sources for emission and carbon gain factors, as well as potential data sources (Table 13).

At the end of this step, all activity data should have a corresponding emission or carbon gain factor. Depending on the choices a community makes for stratification (Step 4) and data availability, some activity data may share emission and/or carbon gain factors.

Timescale for emissions and removals

Emissions and removals occur on different timescales. 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 forest stands will have a much smaller carbon gain factor applied over many years or decades. For each emission or carbon gain factor selected, communities need to choose a time over which the factor applies.

When developing emission factors, there are two main temporal approaches: the 20-year transition approach and the "committed" approach. Inventory compilers should choose one of these approaches and record their decision.

The 20-year transition approach: Under the original GPC guidelines, if land-use conversion took place less than 20 years earlier, the land 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. Essentially, emissions are spread throughout the 20 years following land-use change. This has the advantage of more accurately temporally distributing emissions from land-use change and reflecting the variable speeds of environmental processes. It also reduces inventories' having bursts of emissions during a cycle when those emissions are actually dispersed over several cycles. However, in practice, this complicates the emission calculations, particularly when data available to track changes to the dead organic matter and soil carbon pools are scarce or nonexistent. This approach also requires carrying over emissions from previous inventories into the current inventory, including those up to 20 years preceding a community's baseline "Land" sub-sector inventory.

The "committed" approach: Under the "committed" approach, it is assumed that full or partial loss of the carbon stock—for deforestation (i.e., *Forest Land converted to Non-Forest Land*) and other carbon stock decreases associated with disturbances—occurs at the time change is detected. In other words, the "committed" approach estimates the expected future losses in carbon stock and assigns all of it to the cycle in which it is detected. For community-scale inventories, assuming full or partial loss of carbon stock at the time of detection and reporting the emissions from conversion in the year of detection is a reasonable simplification and reduces the complexity of calculations. This approach will overestimate the actual emissions in the inventory cycle; however, over time the inventory typically self-corrects. Subsequent inventory cycles will capture forest regrowth in deforested areas (if it occurs) and not show emissions from earlier forest loss. While methodologies in the GPC generally quantify emissions and removals released and absorbed during the reporting year, available methodologies (in the Waste sector, for instance) may also estimate the future emissions that result from activities conducted within the reporting year using a similar type of "committed" approach (GPC, Chapter 8).

For CO_2 removals associated with *Non-Forest Land converted to Forest Land*, the timescale can be simplified by applying an annual carbon gain factor associated with the growth of younger stands for the initial inventory cycle and by assuming that the start date for the new stand is the beginning of the inventory. In subsequent inventories, the stand would be assigned to *Forest Land remaining Forest Land* and receive a corresponding annual carbon gain factor in each inventory year that forest biomass continues to increase (if a distinct *Forest Land remaining Forest Land* carbon gain factor is available). Subsequent inventories would capture as an emission any "reversal" that occurred following afforestation or reforestation. In this way, annual inventories over time will capture both emissions and removals in the year in which they occur.

Emission factors for *Forest Land* that changed land use during the period of analysis

Subcategories for which there are activity data shall have carbon densities assigned to them (which may need to be converted from a biomass density to a carbon density by multiplying by a default of 0.47; IPCC 2019b) to be used as the basis of emission factors. For example, if *Forest Land* is stratified by forest type, then each forest type needs a carbon density estimate. The carbon densities should include all ecosystem carbon pools (aboveground biomass, belowground biomass, deadwood, litter, and soil) for completeness.

For all nonsoil carbon pools, this supplement recommends, for simplicity, that the entire carbon density value be assumed to be emitted upon deforestation (IPCC default assumption), unless there is reason to believe otherwise. If full carbon stocks are emitted, then the carbon density value is the same as the emission factor value. If only data on aboveground carbon densities are available, belowground, deadwood, and litter carbon stocks can be estimated using default assumptions (Table 16).

For soil organic carbon in mineral soils on *Forest Land converted to Non-Forest Land*, the amount of carbon emitted from the soil carbon pool depends on the subsequent *Non-Forest Land* use. That is, the fraction of soil carbon retained following forest conversion to the new land use is determined by what the new land use is. The IPCC default assumption is that it takes 20 years for soil carbon stocks to come to a new equilibrium under the new land use and that emissions occur evenly over those 20 years. Annual emissions from soil carbon following a deforestation event can be calculated using Equation 1.

Table 16 Default assumptions for the calculation of belowground biomass carbon, deadwood, and litter carbon densities from aboveground biomass density

Climate	Elevation	Precipitation	Belowground Fraction of Aboveground Biomass	Deadwood Fraction of Aboveground Biomass	Litter Fraction of Aboveground Biomass
Tropical	<2,000 m	<1,000 mm/yr	26%	2%	4%
Tropical	<2,000 m	1,000–1,600 mm/yr	26%	1%	1%
Tropical	<2,000 m	>1,600 mm/yr	26%	6%	1%
Tropical	>2,000 m	All	26%	7%	1%
Temperate/ Boreal	All	All	26%	8%	4%

Note: Belowground carbon fraction is a global average from Mokany et al. (2006). Deadwood and litter carbon fractions are from UNFCCC (2013).

Equation 1 **Emissions from mineral soil carbon**

$$E_{mineral\ soil} = \frac{C_{forest\ soil} - (C_{forest\ soil} \times F)}{D}$$

Description

$E_{mineral\ soil}$	=	The annual change in organic carbon density in soil (t C/ha/yr)
$C_{forest\ soil}$	=	Soil carbon density in *Forest Land* prior to conversion in the top 30 cm (t C/ha)
F	=	Fraction of carbon remaining in new land use after 20 years: conversion to *Cropland*—0.64; conversion to *Settlements* or *Other Land*—0.8; conversion to *Grassland* or *Wetlands*—1 (IPCC 2019b). 0 means all soil organic carbon is emitted over 20 years; 1 means that no soil organic carbon is emitted over 20 years.
D	=	Number of years over which soil organic carbon is assumed to equalize. Default is 20 years.

Source: Adapted from IPCC 2006, vol. 4, chap. 2, equation 2.25

Communities following a "committed emissions" approach, however, can include in the emission factor the full impact of deforestation on soil carbon emissions to simplify the accounting (i.e., incorporate the total change in soil carbon stocks [the numerator in the equation above, without dividing by D] into the emission factor, rather than an annualized value applied over 20 years). In this approach, the correct soil carbon stock is still emitted, i.e.,

$[(C_{forest\ soil} - (C_{forest\ soil} \times F)]$

but entirely during the current inventory cycle.

Carbon gain factors for *Non-Forest Land converted to Forest Land* during the inventory

As with emissions, each subcategory needs to be assigned a carbon gain factor that represents the annual biomass increment of trees on *Non-Forest Land converted to Forest Land* during the inventory cycle. These subcategories can be based on forest type (e.g., broadleaf vs. coniferous), regrowth type (e.g., natural regrowth vs. assisted), and so on. As mentioned above, ideally these carbon gain factors would be distinct from carbon gain factors for *Forest Land remaining Forest Land* by specifically representing removals in young forests.

Emission and carbon gain factors for *Forest Land remaining Forest Land* during the inventory

For undisturbed *Forest Land remaining Forest Land*, the only relevant factors are those for carbon gain, which represent the annual biomass increment of standing forests growing with the community boundary each year. Each *Forest Land* subcategory should have a carbon gain factor. Ideally, as mentioned above, these would be distinct from the carbon gain factors used for *Non-Forest Land converted to Forest Land* by representing older forests.

For disturbed *Forest Land remaining Forest Land*, the only relevant factors are those for emissions, which represent emissions arising from various disturbances due to a loss of forest biomass. Ideally, emission factors would be based on the nature and intensity of disturbance. For example, low-intensity fires might be known to release only a fraction of the carbon stock, rather than all of it. However, if no disturbance-specific emission factors are available, then the emission factor may be assumed to be the same as for *Forest Land converted to Non-Forest Land*, with just the biomass carbon components emitted. This assumes that the other carbon pools (deadwood, litter, soil) are not impacted (per IPCC Tier 1 assumptions for *Forest Land remaining Forest Land*). While disturbed forest may have removals for some portion of the inventory cycle, excluding removals by disturbed forest is a conservative estimate, in that removals in the inventory may be underestimated rather than overestimated.

Step 8: Calculate carbon emissions and removals for *Forest Land*

As shown in Figure 6, Step 8 is the beginning of Stage 3 of the *Forest Land* inventory. In Stage 2, activity data and emission and/or carbon gain factors were compiled. Now, these are combined for each relevant inventory subcategory to calculate forest-related changes in carbon stocks (CO_2 emissions and CO_2 removals) across a community's *Forest Land* (Table 17).

Step 8.1: Calculate emissions from *Forest Land converted to Non-Forest Land*

This calculation corresponds to the top right pink cell of Table 17 (top row of Table 5), which represents areas that changed from *Forest Land* to *Non-Forest Land* during the inventory. Emissions are the area of conversion in each subcategory multiplied by the appropriate emission factor for that subcategory during the inventory (Equation 2). Table 17 shows one box for *Forest Land converted to Non-Forest Land*, but, in many inventories, this may actually be comprised of several different components that reflect emissions from conversion of *Forest Land* to each subsequent land use and/or different *Forest Land* subcategories being converted.

Table 17 **Basic *Forest Land*–focused land-use change matrix with references to relevant chapters and steps**

		Land Use at End of Inventory Cycle	
		Forest Land	*Non-Forest Land*
Land Use at Start of Inventory Cycle	*Forest Land*	$R_{F\rightarrow F\text{-Undisturbed}}$ $E_{F\rightarrow F\text{-Disturbed}}$ Chapter 7, Step 8.3	$E_{F\rightarrow NF}$ Chapter 7, Step 8.1
	Non-Forest Land	$R_{NF\rightarrow F}$ Chapter 7, Step 8.2	Trees on *Non-Forest Land:* $R_{treegain}$, $E_{treeloss}$ Chapter 8, Step 8

Forest Land remaining Forest Land

Non-Forest Land converted to Forest Land

Forest Land converted to Non-Forest Land

Non-Forest Land remaining Non-Forest Land on which changes to trees on *Non-Forest Land* are tracked

Notes: $R_{F\rightarrow F\text{-Undisturbed}}$ = CO_2 removals in undisturbed *Forest Land remaining Forest Land*; $E_{F\rightarrow F\text{-Disturbed}}$ = GHG emissions in disturbed *Forest Land remaining Forest Land*; $R_{NF\rightarrow F}$ = CO_2 removals in *Non-Forest Land converted to Forest Land*; $E_{F\rightarrow NF}$ = GHG emissions in *Forest Land converted to Non-Forest Land*; $R_{treegain}$ = CO_2 removals by trees on *Non-Forest Land remaining Non-Forest Land*; $E_{treeloss}$ = GHG emissions from trees on *Non-Forest Land remaining Non-Forest Land.*

Equation 2 **Emissions from *Forest Land converted to Non-Forest Land***

$$\mathbf{E}_{F\rightarrow NF} = \sum_{i=1}^{n}\sum_{k=1}^{K}(AD_{ik} \times EF_{ik})$$

Description

$E_{F\rightarrow NF}$	=	Emissions from *Forest Land converted to Non-Forest Land* during the inventory (t C)
AD_{ik}	=	Area of *Forest Land* subcategory i converted to *Non-Forest Land* category k (ha)
EF_{ik}	=	Emission factor for each *Forest Land* subcategory i converted to *Non-Forest Land* category k (t C/ha). The same emission factor can be used for multiple combinations of source *Forest Land* subcategories and destination *Non-Forest Land* categories.
i	=	1, 2, 3… n *Forest Land* subcategories
k	=	1, 2, 3… K *Non-Forest Land* categories (i.e., *Cropland*, *Settlements*, *Grassland*, *Wetlands*, *Other Land*).

Source: Adapted from IPCC 2006, vol. 4, chap. 2, equation 2.14.

Sample Calculation 1 estimates the emissions from *Forest Land converted to Non-Forest Land* for two *Forest Land* subcategories. For additional stratification, this calculation would be repeated for each *Forest Land* subcategory of interest i converted to *Non-Forest Land* category k.

Step 8.2: Calculate removals by *Non-Forest Land converted to Forest Land*

This step corresponds to the bottom left light green cell of Table 17 (left column of Table 5), which represents areas that changed from *Non-Forest Land* to *Forest Land* during the inventory. This specifically includes areas of *Non-Forest Land* that became *Forest Land* but are not part of a forest management cycle or natural disturbance. For example, these areas could include restoration projects or spontaneous natural regeneration on lands not managed for forestry; they do not include *Forest Land* that is regenerating after harvest as part of forest management or a natural disturbance (which is covered in Step 8.3). For *Non-Forest Land converted to Forest Land*, CO_2 removals are estimated as the area of forest gain during the inventory multiplied by the appropriate carbon gain factor and by the years of the inventory cycle for each subcategory (Equation 3). *Non-Forest Land converted to Forest Land* can be one category or multiple subcategories if different practices, tree species, ownership classes, and so on are established.

Sample Calculation 1 Emissions for *Forest Land converted to Non-Forest Land*

This example is for a hypothetical community with conversion from broadleaf forest to an agricultural field during a five-year inventory cycle. The calculation is for two forest subcategories, which represent different ownership types (private vs. public).

Data:

- Subcategory 1: Forest type 1 (private land) area of deforestation = 100 ha
- Subcategory 1: Forest type 1 emission factor = 84 t C/ha
- Subcategory 2: Forest type 2 (public land) area of deforestation = 50 ha
- Subcategory 2: Forest type 2 emission factor = 75 t C/ha

Calculations:

- Subcategory 1: Forest type 1 emissions = 84 x 100 = 8,400 t C (over the five-year inventory cycle)
- Subcategory 2: Forest type 2 emissions = 75 x 50 = 3,750 t C (over the five-year inventory cycle)

Total emissions (i.e., decrease in carbon stocks) = 8,400 + 3,750 t C = 12,150 t C (over the five-year inventory cycle)

Equation 3 Removals by *Non-Forest Land converted to Forest Land*

$$R_{F \rightarrow NF} = \sum_{i=1}^{n} \sum_{k=1}^{K} (AD_{ki} \times GF_{ki} \times T)$$

Description

$R_{NF \rightarrow F}$	=	Removals by *Non-Forest Land converted to Forest Land* during the inventory (t C)
i	=	1, 2, 3… n *Forest Land* subcategories
k	=	1, 2, 3… K *Non-Forest Land* subcategories
AD_{ki}	=	Area of *Non-Forest Land* subcategory k converted to *Forest Land* subcategories i (ha)
GF_{ki}	=	Carbon gain factor for each *Non-Forest Land* subcategory k to *Forest Land* subcategory i (t C/ha/year). The same carbon gain factor can be used for multiple combinations of source *Non-Forest Land* subcategories and destination *Forest Land* categories.
T	=	Number of years since the conversion (Chapter 5); if the point in the inventory cycle when the conversion took place is unknown, this supplement recommends using the number of years in the inventory cycle because of the typical lag in detection of new forests when using remote-sensing methods; by the time new trees are detected, they are likely to be several years old already.

Source: Adapted from IPCC 2006, vol. 4, chap. 2, equation 2.9.

Sample Calculation 2 Removals by *Non-Forest Land converted to Forest Land*

This example is for a hypothetical community with some area converted from *Grassland* to pine plantation (subcategory 1) and some area from *Grassland* to a natural forest community as part of a restoration project (subcategory 2). Regrowth is assumed to have occurred during the entire inventory (five years) rather than starting in some specific year of the inventory.

Data:

- Subcategory 1: Forest type 1 new area of *Forest Land* = 100 ha
- Subcategory 1: Forest type 1 carbon gain factor = -0.86 t C/ha/yr
- Subcategory 2: Forest type 2 new area of *Forest Land* = 50 ha
- Subcategory 2: Forest type 2 carbon gain factor = -0.50 t C/ha/yr

Calculations:

- Subcategory 1: Forest type 1 removals = -0.86 x 100 x 5 = -430 t C (over the five-year inventory cycle)
- Subcategory 2: Forest type 2 removals = -0.53 x 50 x 5 = -132.5 t C (over the five-year inventory cycle

Total emissions (i.e., decrease in carbon stocks) = -430 + -132.5 = -562.5 t C (over the five-year inventory cycle)

Sample Calculation 2 estimates the removals by *Non-Forest Land converted to Forest Land*. This calculation would be repeated for each *Non-Forest Land* category of interest (k) converted to *Forest Land* subcategory of interest i, as defined by the activity data and any other classification variable.

Step 8.3: Calculate emissions and removals on *Forest Land remaining Forest Land*

This calculation corresponds to the top left dark green cell of Table 17 (top row of Table 5), which represents areas that remained in a *Forest Land* use throughout the inventory. Because *Forest Land remaining Forest Land* includes removals and emissions (undisturbed and disturbed *Forest Land*, respectively) in different areas and/or at different times during the inventory cycle, it is most transparent to estimate and report carbon gains and losses separately.

There are thus two equations for this category: GHG emissions from disturbed *Forest Land remaining Forest Land* (Equation 4) and CO_2 removals by undisturbed *Forest Land remaining Forest Land* (Equation 5).

Equation 4 Emissions on disturbed *Forest Land remaining Forest Land*

Equation 5 Removals on undisturbed *Forest Land remaining Forest Land*

$$4 \quad E_{F \to F \text{ disturbed}} = \sum_{i=1}^{n} \sum_{j=1}^{J} (AD_{ij} \times EF_{ij})$$

$$5 \quad R_{F \to F \text{ undisturbed}} = \sum_{i=1}^{n} (AD_i \times GF_i \times T)$$

Description

$E_{F \to F \text{ disturbed}}$	=	Emissions from disturbed *Forest Land remaining Forest Land* during the inventory (t C)
$R_{F \to F \text{ undisturbed}}$	=	Removals by undisturbed *Forest Land remaining Forest Land* during the inventory (t C)
AD_{ij}	=	Area of *Forest Land* in subcategory i (of disturbance type j, if applicable) (ha)
i	=	1, 2, 3, …, n forest subcategories
j	=	1, 2, 3, …, J disturbance types
T	=	Number of years in the inventory cycle. See Chapter 5.
EF_{ij}	=	Emission factor for each disturbance type j in subcategory i (t C/ha)
GF_i	=	Carbon gain factor for each subcategory i (average annual carbon gain factor, t C/ha/yr)

Source: Equation 4 adapted from IPCC 2006, vol. 4, chap. 2, equation 2.14; equation 5 adapted from IPCC 2006, vol. 4, chap. 2, equation 2.9.

Sample Calculation 3 Emissions and removals in *Forest Land remaining Forest Land*

This example is for a hypothetical community with two forest types totaling 300 hectares during a five-year inventory. Negative numbers indicate net removal (gain) of carbon from the atmosphere; positive numbers indicate net emissions (loss) of carbon from the atmosphere.

Data:

- Subcategory 1: Forest type 1 undisturbed, area = 80 ha
- Subcategory 2: Forest type 1 disturbed (burned), area = 20 ha
- Subcategory 3: Forest type 2 undisturbed, area = 200 ha
- Subcategory 1: Forest type 1 carbon gain factor = -1.46 t C/ha/yr
- Subcategory 2: Forest type 1 emission factor (carbon only) = 78.3 t C/ha
- Subcategory 3: Forest type 2 carbon gain factor = -2.24 t C/ha/yr

Calculations:

- Subcategory 1: Forest type 1 removals = -1.46 x 80 x 5 = -584 t C
- Subcategory 2: Forest type 1 emissions (carbon only) = 78.3 x 20 = 1,566 t C
- Subcategory 3: Forest type 2 removals = -2.24 x 200 x 5 = - 2,240

Total gross C removals (i.e., increase in carbon stocks in undisturbed forest = -584 – 2,240 = -2,824 t C (for the five-year inventory cycle)

Total gross C emissions (i.e., decrease in carbon stocks in disturbed forest) = 1,566 t C (for the five-year inventory cycle)

Sample Calculation 3 provides an example of calculating emissions from and removals by disturbed and undisturbed *Forest Land remaining Forest Land*.

Alternatively, annual volumes of timber or fuelwood harvesting occurring within the inventory boundary during the inventory may be used to estimate carbon loss (emissions) from removal of forest biomass (Equations 6 and 7). In these cases, annual harvest volumes (m^3/yr) are combined with a biomass conversion and expansion factor (BCEF) to estimate the annual loss of aboveground forest biomass, rather than estimating an emission factor to multiply by the extent of harvest area during the inventory (as detected as loss of tree cover in land-cover change maps). With this approach, the area of forest disturbance from other disturbance data sources (e.g., aerial imagery) and attributed to harvest or fuelwood collection areas shall be ignored to avoid double-counting emissions from wood harvest.

Default BCEF values (in units of tonnes biomass/m^3 of wood volume) for various climate zones and general forest types can be found in Table 4.5 of the 2006 IPCC Guidelines (IPCC 2006). Likewise, net annual increment data (including bark) can be used to estimate GF_i by applying a biomass conversion and expansion factor (IPCC 2006, vol. 4, chap. 2, equation 2.10). Use of timber statistics to estimate biomass removals is likely to be more accurate than using remote-sensing data in cases of selective logging or fuelwood harvest practices that may not be detected as a loss of forest cover within a community's land-cover change maps.

Equation 6 **Carbon loss in biomass of wood removals on *Forest Land remaining Forest Land***

Equation 7 **Carbon loss in biomass of fuelwood removals on *Forest Land remaining Forest Land***

$$6 \quad E_{F\rightarrow F\ \text{disturbed - wood removals}} = H \times BCEF_R \times (1 + R) \times CF \times T$$

$$7 \quad E_{F\rightarrow F\ \text{disturbed - fuelwood}} = [(FG_{trees} \times BCEF_R \times (1 + R)) + FG_{part} \times D] \times CF \times T$$

Description

$E_{F\rightarrow F\ \text{disturbed - wood removals}}$	=	Carbon loss due to biomass removals on disturbed *Forest Land remaining Forest Land* during the inventory (t C)
$E_{F\rightarrow F\ \text{undisturbed - fuelwood}}$	=	Carbon loss due to fuelwood removals on disturbed *Forest Land remaining Forest Land* during the inventory (t C)
H	=	Annual wood removals, roundwood (m^3/yr)
R	=	Ratio of belowground biomass to aboveground biomass. Default is 0.26.
CF	=	Carbon fraction of dry matter. Default is 0.47 (IPCC 2019b).
$BCEF_R$	=	Biomass conversion and expansion factor
FG_{trees}	=	Annual volume of fuelwood removal of whole trees (m^3/yr)
FG_{part}	=	Annual volume of fuelwood removal as tree parts (m^3/yr)
D	=	Basic wood density (t aboveground biomass/m^3, found in IPCC (2006), vol. 4, chap. 2, tables 4.13 and 4.14)
T	=	Number of years in the inventory cycle. See Chapter 5.

Source: Both adapted from IPCC 2006, vol. 4, chap. 2, equations 2.12 and 2.13.

Step 9: Calculate non-CO_2 emissions for *Forest Land* (if applicable)

As mentioned in Section 2.2, a major source of non-CO_2 emissions from the “Land” sub-sector is CH_4 and N_2O emissions from biomass burning during prescribed fires or wildfires. Other non-CO_2 sources, such as soil N_2O emissions with mineral fertilization and organic amendments and CH_4 emission from forested wetlands, may also occur, but this supplement does not cover them because they are minor sources in most communities.

CO_2 emissions from fires on *Forest Land* are counted as CO_2 emissions due to disturbances and calculated in Step 8. Non-CO_2 emissions from fires are calculated as the sum of the area of *Forest Land* burned multiplied by the fuel available for combustion per unit area, which considers both the fraction of available fuel combusted and the mass of each GHG emitted per unit of fuel combusted. Emissions of each gas are estimated individually (Equations 8 and 9) and then are summed to give the total GHG emissions due to fires (Equation 10). If no or minimal fires occurred during the inventory period, their absence from the inventory shall be reported with the appropriate notation key.

Equation 8 Methane emissions from fires on *Forest Land*
Equation 9 Nitrous oxide emissions from fires on *Forest Land*
Equation 10 Non-CO_2 emissions from fires on *Forest Land*

$$8 \quad E_{CH4} = A_{burn} \times M_B \times C_f \times EF_{CH4} \times 10^{-3} \times GWP_{CH4}$$

$$9 \quad E_{N2O} = A_{burn} \times M_B \times C_f \times EF_{N2O} \times 10^{-3} \times GWP_{N2O}$$

$$10 \quad E_{\textit{Forest Land} \text{ non-CO2}} = E_{CH4} + E_{N2O}$$

Description

$E_{\textit{Forest Land} \text{ non-CO2}}$	=	Total non-CO_2 emissions from forest fires (t CO_2e)
E_{N2O}	=	Amount of methane emissions from forest fires (t CH_4)
E_{CH4}	=	Amount of nitrous oxide emissions from forest fires (t N_2O)
A_{burn}	=	Area of *Forest Land* burned (ha) during the inventory cycle
M_B	=	Mass of fuel available for combustion (t biomass/ha). This includes biomass, ground litter, and deadwood. When Tier 1 methods are used, then litter and deadwood pools are assumed to be zero, except where there is a land-use change, in which case these pools are included in the fuel available to burn. Carbon densities will need to be converted to biomass densities by dividing by 0.47 first (IPCC 2019b).
C_f	=	Combustion factor (dimensionless, see Appendix C for values [IPCC 2006, table 2.6])
EF_{CH4}	=	Emission factor for CH_4 (g/kg dry matter burned, see Appendix C for values [IPCC 2006, table 2.5])
EF_{N2O}	=	Emission factor for N_2O (g/kg dry matter burned, see Appendix C for values [IPCC 2006, table 2.5])
GWP_{CH4}	=	27.2 (global warming potential is dimensionless; *Source:* IPCC 2021).
GWP_{N2O}	=	273 (global warming potential is dimensionless; *Source:* IPCC 2021).

Source: All three equations adapted from IPCC 2006, vol. 4, chap. 2, equation 2.27; also see equation 10.6 in GPC, chap. 10.

The equation includes multiplication by 10^{-3} to convert EF_{CH4} and EF_{N2O} from g/kg dry matter burned to g/tonnes dry matter burned. Sample Calculation 4 provides an example of calculating non-CO_2 emissions from fires in *Forest Land remaining Forest Land*.

The area of *Forest Land* burned during the inventory may be available from satellite observations or local mapping of fire extents (Case Study 3). The mass of fuel available for combustion (M_B) is often based on the forest biomass density estimated for the community (see Step 3). The combustion factors (C_f) and emission factors EF_{CH4} and EF_{N2O} may be based on the default values in the 2006 IPCC guidelines (IPCC 2019b), which vary based on vegetation type (Appendix C); it is unlikely that local data will be available for these parameters. Which default value to apply should be based on the closest match of available vegetation types in the IPCC lookup table to the community's forest types. Emissions of each non-CO_2 gas (CH_4, N_2O) are then converted into CO_2 equivalents (CO_2e) using 100-year global warming potential (GWP) values published in the IPCC's Sixth Assessment report or those used at the national level.

Sample Calculation 4 Non-CO_2 emissions from fires in *Forest Land remaining Forest Land*

This example is for a hypothetical community in a temperate climate in which 20 ha burned during a five-year inventory. CO_2 emissions are calculated in Sample Calculation 3, and non-CO_2 emissions are calculated here (using values from Appendix B).

Data:

- Forest type 1 disturbed, burned area = 20 ha
- EF_{CH4} (nontropical forest) = 4.7 g/kg dry matter
- EF_{N2O} (nontropical forest) = 0.26 g/kg dry matter
- C_f ("other temperate forest") = 0.45
- M_B = 166.6 t biomass/ha (from Sample Calculation 3, with C density of 78.3 t C/ha converted to biomass by dividing by 0.47)

Calculations:

- E_{CH4} = 20 ha x 166.6 t biomass/ha x 0.45 x 4.7 g/kg x 10^{-3} kg/g x 27.2 = 192 t CO_2e
- E_{N2O} = 20 ha x 166.6 t biomass/ha x 0.45 x 0.26 g/kg x 10^{-3} kg/g x 273 = 106 t CO_2e
- E_{fire} = 192 + 106 = 298 t CO_2e

- **Non-CO_2 emissions** = 298 t CO_2e (for the five-year inventory cycle)

Step 10: Calculate gross emissions, gross removals, and net *Forest Land* GHG flux during the inventory and annualize the results into t CO_2e/year

This step calculates the gross emissions (all *Forest Land* sources of emissions), gross removals (all *Forest Land* sources of removals), and net *Forest Land* GHG flux in t CO_2e/year as the sum of emissions and removals in Steps 8 and 9. Emissions and removals shall be calculated and reported separately for more transparent addition with other sectors (Equations 11 and 12); optionally, net flux may be calculated as a way to summarize the "Land" sub-sector only (Equation 13). Estimates shall be reported as annual CO_2e fluxes rather than totals over the inventory cycle (as required by the GPC) to facilitate comparisons with other sectors and other cycles, as long as each estimate was developed using consistent methods, data, and approaches to ensure comparability over time. This can also be combined with the annual values from trees on *Non-Forest Land* in Chapter 8, Step 11.

Sample Calculation 5 combines each of the *Forest Land* components into a single estimate of annual net GHG flux.

Equation 11 Gross emissions from *Forest Land*
Equation 12 Gross removals by *Forest Land*
Equation 13 Net GHG flux on *Forest Land*

$$\textbf{11 Gross Emissions}_{\text{Forest Land}} = \frac{[(\frac{44}{12}) \times (E_{F\to NF} + E_{F\to F\ disturbed})] + E_{\text{Forest Land non-CO2}}}{T}$$

$$\textbf{12 Gross Removals}_{\text{Forest Land}} = \frac{(\frac{44}{12}) \times (R_{NF\to F} + R_{F\to F\ undisturbed})}{T}$$

$$\textbf{13 Net GHG Flux}_{\text{Forest Land}} = \text{Gross Emissions}_{\text{Forest Land}} + \text{Gross Removals}_{\text{Forest Land}}$$

Description

$\text{Gross Emissions}_{\text{Forest Land}}$	=	Average annual gross GHG emissions from *Forest Land* (t CO_2e/yr)
$\text{Gross Removals}_{\text{Forest Land}}$	=	Average annual gross CO_2 removals by *Forest Land* (t CO_2/yr)
$\text{Net GHG Flux}_{\text{Forest Land}}$	=	Average annual net GHG flux from *Forest Land* (t CO_2e/yr) (reflects the net balance of emissions of CO_2, CH_4, and N_2O and removals of CO_2)
$E_{F\to NF}$	=	Emissions from *Forest Land converted to Non-Forest Land* during the inventory (t C). This value is positive. From Step 8.1, Equation 2.
$R_{NF\to F}$	=	Removals by *Non-Forest Land converted to Forest Land* during the inventory (t C). This value is negative. From Step 8.2, Equation 3.
$E_{F\to F\ disturbed}$	=	Emissions from disturbed *Forest Land remaining Forest Land* during the inventory (t C). This value is positive. From Step 8.3, Equations 4, 6, and 7 (if applicable).
$R_{F\to F\ undisturbed}$	=	Removals by undisturbed *Forest Land remaining Forest Land* during the inventory (t C). This value is negative. From Step 8.3, Equation 5.
$GHG_{\text{Forest Land non-CO2}}$	=	CH_4 and N_2O emissions from biomass burning during prescribed fires or wildfires on *Forest Land* (t CO_2e). This value is positive. From Step 9, Equation 10.
T	=	Number of years in the inventory cycle. See Chapter 5.
$\frac{44}{12}$	=	Conversion factor for carbon to CO_2, based on the ratio of their molecular weights.

Source: All three equations adapted from IPCC 2006, vol. 4, chap. 2, equations 2.1 and 2.7.

Sample Calculation 5 Annual gross emissions, gross removals, and net GHG flux from *Forest Land*

This example uses the figures from Sample Calculations 1, 2, 3, and 4. All components are on the same five-year cycle.

Data:

- $E_{F\to NF}$ = 12,150 t C
- $R_{NF\to F}$ = -562.5 t C
- $R_{F\to F-undisturbed}$ = -2,824 t C
- $E_{F\to F-disturbed}$ = 1,566 t C
- $E_{\text{Forest Land non-CO2}}$ = 298 t CO_2e

$$\textbf{Gross emissions}_{\text{Forest Land}} = \frac{[(\frac{44}{12}) \times (12{,}150 + 1{,}566)] + 298}{5} = 10{,}118 \text{ t } CO_2\text{e/yr}$$

$$\textbf{Gross removals}_{\text{Forest Land}} = \frac{(\frac{44}{12}) \times (-562.5 - 2{,}824)}{5} = 2{,}484 \text{ t } CO_2\text{/yr}$$

$$\textbf{Net GHG Flux}_{\text{Forest Land}} = 10{,}118 - 2{,}484 = 7{,}634 \text{ t } CO_2\text{e/yr}$$

8 *Calculating GHG fluxes for trees on* Non-Forest Land

Whereas Chapter 7 addressed the calculation of GHG fluxes for a community's *Forest Land* and related changes over the inventory cycle, this chapter provides step-by-step guidance for estimating GHG fluxes from tree biomass for land uses and land-use changes that do not involve *Forest Land;* that is, the area of a community's land that falls within the *Non-Forest Land* categories of the land-use change matrix (*Cropland*, *Grassland*, *Wetlands*, *Settlements*, *Other Land*). In other words, this chapter addresses the *Non-Forest Land* steps needed to complete Stages 1–3 of the inventory as shown in Figure 7. Trees are embedded in *Non-Forest Land* and are collectively referred to here as "trees on *Non-Forest Land*" (Table 6). Inventories that include the "Land" sub-sector shall include emissions and removals for trees on *Non-Forest Land*. A link to a downloadable spreadsheet with a worked sample inventory can be found in Appendix D.

Trees on *Non-Forest Land* may be significant contributors to GHG fluxes relative to *Forest Land*, particularly in cities which have little area of *Forest Land*. For cities, the *Settlements remaining Settlements* cell of the land-use change matrix in Table 5 will likely be the focus, as most urban land area with tree cover will be classified as such. Other examples of trees on *Non-Forest Land* include agroforestry systems in *Cropland* and sparse tree cover in *Grassland*. They can be individual trees, like in small yards, or larger clumps of trees, like in urban parks.

Both woody and herbaceous vegetation are present in land uses outside *Forest Land*, but for the purposes of this supplement, trees on *Non-Forest Land* are considered the woody perennial vegetation in all *Non-Forest Land* use classes. This supplement includes only the woody component of vegetation 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 other carbon pools and emissions sources in *Non-Forest Land* (e.g., soil carbon emissions, grassland fires) is not covered in this supplement.

The same general steps apply for calculating GHG fluxes associated with trees outside of forests as for GHG fluxes on *Forest Land*: the calculation of activity data, development of emission and carbon gain factors, and the calculation of GHG fluxes. The main difference is that unlike for *Forest Land*, activity data generally do not need to be corrected because tree-canopy changes are not related to land-use changes (see Chapter 7, Step 6b). Although the steps are presented in the specific order listed below, they may be done iteratively, particularly the data selection cycle steps. Often, as data are compiled and preliminary calculations are completed, earlier steps may need to be revisited and adjusted. As for Chapter 7 on *Forest Land*, much of Stage 1 below is covered in Chapters 4–6, but it is summarized here so that all steps related to calculating GHG fluxes for trees on *Non-Forest Land* are contained in a single chapter.

Step 1: Delineate *Non-Forest Land* area

Stage 1: Explore and select data sources (the "data selection cycle")

Step 2: Select source of activity data for trees on *Non-Forest Land* (Chapter 6)

Step 3: Select the inventory cycle for trees on *Non-Forest Land* (Chapter 5)

Step 4: Select subcategories for *Non-Forest Land* (Chapter 4)

Step 5: Select corresponding emission and carbon gain factors for trees on *Non-Forest Land* (Chapter 6)

Stage 2: Prepare and assign activity data, emission factors, and carbon gain factors

Step 6: Calculate activity data for trees on *Non-Forest Land*

Step 7: Develop emission and carbon gain factors for trees on *Non-Forest Land* and match them with activity data

Stage 3: Calculate, sum, and annualize GHG fluxes

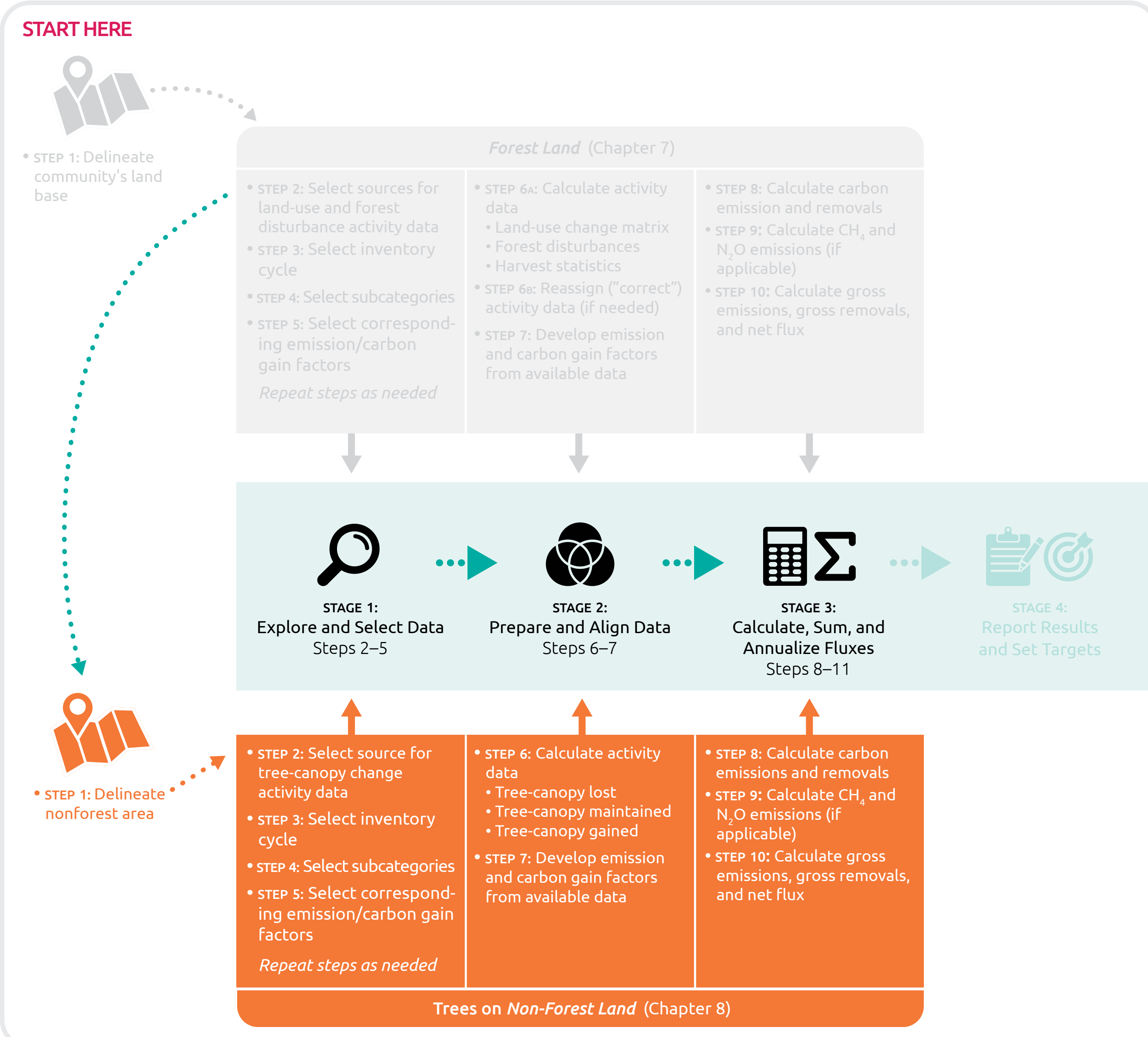
Step 8: Calculate carbon emissions and removals for trees on *Non-Forest Land*

Step 9: Calculate non-CO_2 emissions for trees on *Non-Forest Land* (if applicable)

Step 10: Calculate gross emissions, gross removals, and net GHG flux for trees on *Non-Forest Land* during the inventory and annualize the results into t CO_2e/year

Step 11: Calculate annual gross emissions, annual gross removals, and annual net GHG flux from *Forest Land* and trees on *Non-Forest Land*

Figure 7 Steps for completing the trees on *Non-Forest Land* GHG inventory

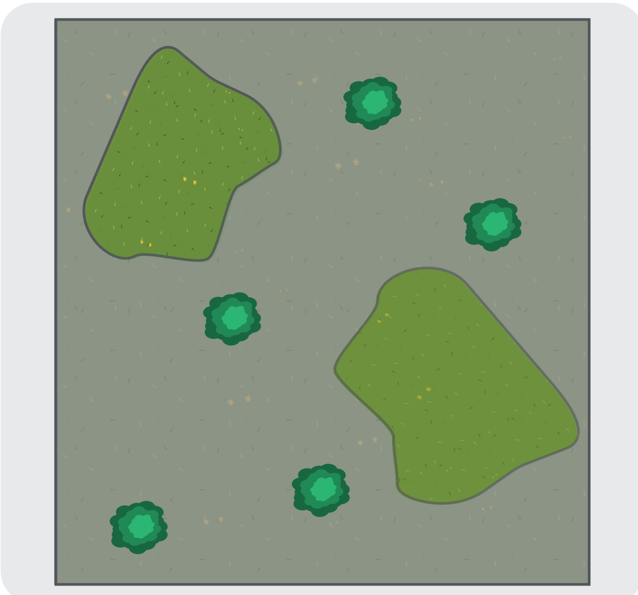


Note: CH_4 = methane; N_2O = nitrous oxide.
Source: Authors.

Step 1: Delineate *Non-Forest Land* area

Selection of the geographical boundary of the inventory was addressed in Chapter 4. The boundary for the *Non-Forest Land* inventory will be the same as for the *Forest Land* inventory (Chapter 7, Step 1). To both exclusively and exhaustively divide the inventory area, *Non-Forest Land* shall be defined and delineated. This requires selecting land-use data (Chapter 7, Step 2) and identifying all areas that do not fall within land classified as *Forest Land* at the end of the inventory (Figure 8). Only these areas are used for completing the steps below.

Figure 8 Delineation of *Forest Land* and *Non-Forest Land*, for use in estimating GHG fluxes from trees on *Non-Forest Land*



Note: Forest Land at end of inventory is shown as green patches, *Non-Forest Land* is shown as gray background, with individual trees on *Non-Forest Land* (green circles) scattered within it.
Source: Authors.

Step 2: Select source of activity data for trees on *Non-Forest Land*

GHG inventories that include the "Land" sub-sector of AFOLU shall include trees on *Non-Forest Land*. Considerations for selecting activity data for trees on *Non-Forest Land* were addressed in Chapter 6 (Table 15).

Step 3: Select the inventory cycle for trees on *Non-Forest Land*

This step was addressed in Chapter 5. The inventory cycle for trees on *Non-Forest Land* should be the same as or as close as possible to the cycle chosen for *Forest Land*. If the cycles for *Non-Forest Land* and *Forest Land* are different (Table 9), the results from both can still be annualized and combined using their respective cycle lengths. The reason for selecting the inventory years included in an inventory cycle for trees on *Non-Forest Land* shall be documented, including, if applicable, the reasons why the monitoring period differs from that for *Forest Land*.

Step 4: Select subcategories for *Non-Forest Land*

The simplest way to conduct and present a GHG inventory for trees on *Non-Forest Land* is by combining all *Non-Forest Land* into a single subcategory, or stratum (combine 25 orange cells of Table 5 into one orange cell of Table 6). However, this may not always be the most accurate or useful way to conduct or report the inventory. In some situations, stratifying trees on *Non-Forest Land* into additional subcategories (by ownership, ward or municipality, land use, etc.) may improve analysis, reporting, and/or design of mitigation policies. For example, subcategorizing *Non-Forest Land* by land ownership can provide additional insights into how GHG fluxes can be managed (Table 18). Note that, unlike land-use change matrices, the intention of a matrix like Table 18 is not to track changes between private and public ownership, since areas of these changes are likely to be zero or very low. Rather, the intention of stratification is to split cells within *Non-Forest Land remaining Non-Forest Land* into subcategories that are useful for the goals of the inventory and climate action planning process or designing and monitoring policies within specific *Non-Forest Land* classes. For example, a community may wish to collect activity data within specific *Non-Forest Land* subcategories to track GHG fluxes associated with distinct urban areas, different community park and recreation areas within the *Settlements remaining Settlements* class, or different agroforestry systems within the *Cropland remaining Cropland* or *Grassland remaining Grassland* classes.

Because there are likely to be few options for choosing emission and carbon gain factors for trees on *Non-Forest Land*, stratification is generally done to improve the granularity of reporting rather than to improve the accuracy of the inventory by using more finely tuned factors.

Establishing a *Non-Forest Land* stratification system for identifying subcategories before compiling activity data for trees on *Non-Forest Land* is particularly important if photointerpretation or point sampling of high-resolution imagery will be used to collect it, rather than wall-to-wall mapping of the tree canopy (Case Study 2). Subcategories must be delineated beforehand to ensure that sufficient points are sampled in each subcategory, and may be difficult to revise later.

Table 18 Land-use change matrix with *Non-Forest Land* disaggregated by ownership

		Land Use at End of Inventory Cycle	
		Non-Forest Land (public)	*Non-Forest Land (private)*
Land Use at Start of Inventory Cycle	*Non-Forest Land* (public)	*Non-Forest Land*—public *remaining* *Non-Forest Land*—public	*Non-Forest Land*—public *converted to* *Non-Forest Land*—private
	Non-Forest Land (private)	*Non-Forest Land*—private *converted to* *Non-Forest Land*—public	*Non-Forest Land*—private *remaining* *Non-Forest Land*—private

Notes: In this example, almost all *Non-Forest Land*, and therefore GHG fluxes from trees on *Non-Forest Land*, are expected to be in the top-left and bottom-right cells because land is not expected to change ownership during the inventory.

Each cell has its own set of activity data (loss, gain, and maintenance of trees on *Non-Forest Land*). Cells involving *Forest Land* are not shown.

Stratification can be achieved by intersecting *Non-Forest Land* with geospatial boundaries of the desired sub-categories. Stratification was discussed further in Chapter 4.

Step 5: Select corresponding emission and carbon gain factors for trees on *Non-Forest Land*

As mentioned, data available for estimating emission and carbon gain factors for trees on *Non-Forest Land* are likely to be much scarcer than for estimating emission and carbon gain factors for *Forest Land*; Tier 1 IPCC defaults, particularly for carbon gain factors, may be all that is available for a community to use. Every subcategory shall have a corresponding emission and/or carbon gain factor, although the factors do not need to be unique to every *Non-Forest Land* subcategory (i.e., subcategories can share the same emission and/or carbon gain factors). Considerations for selecting emission and carbon gain factors, and IPCC Tier 1 defaults, were covered in Section 6.4.

Step 6: Calculate activity data for trees on *Non-Forest Land*

At a minimum, activity data needed for calculating tree-related GHG fluxes on *Non-Forest Land* include the categories listed below, which should reflect total areas (in hectares) of tree crown cover or, alternatively, total tree counts over the inventory cycle (not annualized). These activity data can be disaggregated according to the subcategories chosen in Step 4. The approach to calculating activity data for trees on *Non-Forest Land* entirely depends on the data used. The key requirement is that the area of tree cover or number of trees on *Non-Forest Land* lost, gained, and maintained can be calculated for each subcategory during the inventory. If manual photointerpretation or point count methods are used to estimate tree canopy in multiple years, this stage of data collection may take substantially longer than calculating *Forest Land* activity data from existing land-use change and/or disturbance maps.

Area of tree canopy (or tree counts) lost on *Non-Forest Land* during the inventory cycle. If it occurs, loss of tree canopy is likely to be one of the largest sources of GHG emissions from *Non-Forest Land* during the inventory. The activity data are estimated as the total (gross) area of tree canopy lost or total number of trees lost during the inventory cycle.

Area of tree canopy (or tree counts) gained and maintained on *Non-Forest Land* during the inventory cycle. Unlike for *Forest Land*, where activity data for *Forest Land remaining Forest Land* and *Non-Forest Land converted to Forest Land* are calculated separately, the areas of tree canopy gained in *Non-Forest Lands* may be difficult to detect from the area of tree canopy maintained over time, particularly if the inventory cycle is relatively short (e.g., five years or less). Therefore, the gain and maintenance of tree canopy in *Non-Forest Lands* during the inventory cycle may be combined into a single activity data value for trees gained and maintained outside forests. This can be calculated as the average of the canopy area or number of trees on *Non-Forest Land* at the start and end of the inventory cycle.

Step 7: Develop emission and carbon gain factors for trees on *Non-Forest Land* and match them with activity data

Chapter 6 included some general considerations for selecting data sources for emission and carbon gain factors for trees on *Non-Forest Land*. However, these are highly variable and generally not well characterized. As with activity data, the degree of accuracy and precision that can be achieved in estimating nonforest-related GHG fluxes will depend on the local specificity of the data available from which to develop emission and carbon gain factors for different areas.

At the end of this step, all activity data should have a corresponding emission or carbon gain factor. Depending on the inventory stratification (Step 4) and data availability, some activity data may share emission and/or carbon gain factors.

Timescale for emissions and removals

As with *Forest Land*, emissions and removals occur on different timescales for trees on *Non-Forest Land*. For example, in urban areas, canopy loss from pruning or mortality will produce an initial pulse of emissions that occurs at the time of the event, whereas canopy growth or expansion will have a much smaller carbon gain factor applied over many years or decades as the trees grow. For each emission or carbon gain factor developed, communities need to choose a time over which the factor applies. As with *Forest Land*, the "committed" approach (in which emissions are assigned to the year—or inventory—that loss of tree canopy outside forests was detected) simplifies emissions calculations. For removals, newly detected tree canopy outside forests can be assigned a "new growth" carbon gain factor for that inventory and then an "established" carbon gain factor for subsequent inventories, if distinct carbon gain factors are available. Alternatively, more generic carbon gain factors can be combined with the average area of tree canopy, which includes both tree canopy maintained and tree canopy gained during the inventory.

Carbon removals by trees on *Non-Forest Land* should be included in every year of the inventory, based on the assumption that trees continue to gain biomass over time unless a disturbance is observed. Carbon emissions from pruning, mortality, or other disturbances are recorded in the inventory as an emission, based on loss of trees and/or tree crown area.

Depending on the data available on a community's tree species, planting density, and location of its population of trees on *Non-Forest Land*, a community may wish to define an "active growing period" (AGP) based on the average age of the tree population. The IPCC AGP default is 20 years. During the AGP, trees on *Non-Forest Land* are assumed to be net sinks for carbon, as quantified by the carbon gain factor. Communities with a tree population older than the AGP may set net carbon removals for trees on *Non-Forest Land* in the inventory as zero, based on the assumption that any increases in biomass carbon in trees on *Non-Forest Land* are offset by losses from pruning and mortality. If this assumption is made, neither removals nor emissions for trees on *Non-Forest Land* would be counted in the GHG inventory. However, this supplement recommends that communities collect data to monitor changes in tree canopy or tree counts so that emissions and removals can be tracked separately, rather than assuming a net flux of zero.

Emission factors for loss of trees on *Non-Forest Land*

All *Non-Forest Land* subcategories for which there are activity data shall have carbon densities for trees on *Non-Forest Land* assigned to them (which may need to be converted from a biomass density by multiplying by a default of 0.47; IPCC 2019b). Loss of trees on *Non-Forest Land* is assumed to affect only the aboveground and belowground biomass carbon pools, not deadwood, litter, or soil carbon, unless data are available to include these non-biomass pools.

Carbon gain factor for trees on *Non-Forest Land* that was gained and maintained

Because carbon gain factors are not likely to be available to apply different rates to removals occurring in newly established trees and existing trees on *Non-Forest Land* (their activity data are combined), one carbon gain factor may be used for each *Non-Forest Land* subcategory. However, if separate areas of canopy gained and maintained are used for activity data and different carbon gain factors are available, such as for younger and older trees, then these may be applied. Likewise, if the number of trees gained and maintained are available separately, their removals can be calculated separately, with distinct carbon gain factors, if available.

Step 8: Calculate carbon emissions and removals for trees on *Non-Forest Land*

As shown in Figure 7, Step 8 is the beginning of Stage 3 of the trees on *Non-Forest Land* GHG inventory. In Stage 2, activity data and emission or carbon gain factors were compiled. Now, these are combined for each relevant inventory subcategory to calculate tree-related changes in carbon stocks (CO_2 emissions and CO_2 removals) across a community's *Non-Forest Land*.

Calculating emissions and removals for trees on *Non-Forest Land* is slightly different from calculating emissions and removals for *Forest Land*:

- For *Forest Land*, emissions and removals are calculated separately for *Forest Land remaining Forest Land* (Step 8.1), *Forest Land converted to Non-Forest Land* (Step 8.2), and *Non-Forest Land converted to Forest Land* (Step 8.3).
- For trees on *Non-Forest Land*, emissions from gross loss of tree canopy are calculated separately, while removals resulting from the maintenance and gain of tree canopy may be calculated together.

In other words, changes in carbon stocks for trees on *Non-Forest Land* reflect the net balance of removals by canopy maintained and gained against the emissions from tree-canopy loss (Equations 14 and 15).

Sample Calculation 6 shows how to estimate changes in carbon stocks for trees on *Non-Forest Land*.

Equation 14 Emissions from trees lost on *Non-Forest Land*
Equation 15 Removals by trees gained and maintained on *Non-Forest Land*

14 $$E_{treeloss} = \sum_{k=1}^{K} (AD_{treeloss\_k} \times EF_k)$$

15 $$R_{treegain} = \sum_{k=1}^{K} (AD_{trees_k} \times GF_k \times T)$$

Description

$E_{treeloss}$	=	Gross emissions from trees lost on *Non-Forest Land* during inventory T (t C)
$R_{treegain}$	=	Gross removals by trees gained and maintained on *Non-Forest Land* during inventory T (t C)
$AD_{treeloss\_k}$	=	Area of gross tree-canopy loss on *Non-Forest Land* or number of trees lost during the inventory in *Non-Forest Land* category *k* (ha or trees)
AD_{trees_k}	=	Average area of *Non-Forest Land* with tree-canopy cover or average number of trees during the inventory in *Non-Forest Land* category *k* (ha or trees)
EF_k	=	Average emission factor from loss of trees on *Non-Forest Land* subcategory *k* (t C/ha or t C/tree)
GF_k	=	Average carbon gain factor of trees on *Non-Forest Land* subcategory *k* (t C/ha/yr or t C/tree/yr)
k	=	1,2,3, …, K *Non-Forest Land* subcategories
T	=	Number of years in the inventory cycle. See Chapter 5.

Source: Both equations adapted from IPCC 2006, vol. 4, chap. 8, equations 8.2 and 8.3.

Sample Calculation 6 **Emissions and removals for trees on *Non-Forest Land***

This example is for a hypothetical community that is tracking two *Non-Forest Land* subcategories over a five-year inventory: trees in *Settlements* (urban trees) and trees on all other *Non-Forest Land*. The inventory is based on area of canopy rather than count of trees.

Data:

- Subcategory 1: Tree canopy area maintained = 50 ha; tree loss area = 1 ha
- Subcategory 2: Tree canopy area maintained = 200 ha; tree gain area = 10 ha; tree loss area = 2 ha
- Subcategory 1 and 2: Carbon gain factor (new and standing trees) = -2.8 t C/ha/yr (IPCC Tier 1 default)
- Subcategory 1: Emission factor (tree loss) = 100 t C/ha
- Subcategory 2: Emission factor (tree loss) = 60 t C/ha

Calculations:

- Subcategory 1 removals = (-2.8 x 50) x 5 = -700 t C
- Subcategory 1 emissions = (100 x 1) = 100 t C
- Subcategory 2 removals = (-2.8 x (210 – 200)/2) x 5 = -2,870 t C
- Subcategory 2 emissions = (60 x 2) = 120 t C

Total gross C removals (i.e., increase in carbon stocks in gained and maintained tree canopy) = -700 – 2,870 = -3,570 t C (for the five-year inventory cycle)

Total gross C emissions (i.e., decrease in carbon stocks in lost tree canopy = 100 + 120 = 220 t C (for the five-year inventory cycle)

Total net C flux (i.e., total net change in carbon stocks) = 220 – 3,570 = -3,350 t C (for the five-year inventory cycle)

Step 9: Calculate non-CO_2 emissions for trees on *Non-Forest Land* (if applicable)

As mentioned in Section 2.2, a major source of non-CO_2 emissions from the "Land" sub-sector is CH_4 and N_2O emissions from biomass burning during prescribed fires or wildfires. Other non-CO_2 sources, such as soil N_2O emissions with mineral fertilization and organic amendments and CH_4 emission from forested wetlands, may also occur, but this supplement does not cover them because they are minor sources in most communities.

CO_2 emissions from fires occurring on *Non-Forest Land* are counted as CO_2 emissions and calculated in Step 8. Non-CO_2 emissions from fires occurring on *Non-Forest Land* are calculated identically as for *Forest Land* that burns; that is, the area burned multiplied by the fuel available for combustion per unit area, which considers both the fraction of available fuel combusted and the mass of each GHG emitted per unit of fuel combusted. Emissions of each gas are estimated individually and then are summed to give the total GHG emissions due to fire. Refer to Chapter 7, Step 9, for equations and more information.

Step 10: Calculate gross emissions, gross removals, and net GHG flux for trees on *Non-Forest Land* during the inventory and annualize the results into t CO_2e/year

This step calculates the gross emissions (all sources of emissions for trees on *Non-Forest Land*, Equation 16), gross removals (all sources of removals for trees on *Non-Forest Land*, Equation 17), and net GHG flux (Equation 18) for trees on *Non-Forest Land* in t CO_2e/year as the sum of emissions and removals in Steps 8 and 9. Emissions and removals shall be calculated and reported separately for more transparent addition with other sectors; optionally, net flux may be calculated as a way to summarize the "Land" sub-sector only. Estimates shall be reported as annual CO_2e fluxes rather than totals over the inventory cycle (as required by the GPC) to facilitate comparisons with other sectors and other cycles, as long as each estimate was developed using consistent methods, data, and approaches to ensure comparability over time. This can also be combined with the annual values from *Forest Land* from Chapter 7, Step 10, in Step 11 below.

Equation 16 **Gross emissions from trees on *Non-Forest Land***
Equation 17 **Gross removals by trees on *Non-Forest Land***
Equation 18 **Net GHG flux from trees on *Non-Forest Land***

16 $$\textbf{Gross Emissions}_{trees} = \frac{[(\frac{44}{12}) \times E_{treeloss}] + E_{trees\ non\text{-}CO2}}{T}$$

17 $$\textbf{Gross Removals}_{trees} = \frac{(\frac{44}{12}) \times R_{treegain}}{T}$$

18 $$\textbf{Net GHG Flux}_{trees} = \text{Gross Emissions}_{trees} + \text{Gross Removals}_{trees}$$

Description

Gross Emissions_{trees}	=	Average annual gross GHG emissions from trees on *Non-Forest Land* (t CO_2e/yr)
Gross Removals_{trees}	=	Average annual gross CO_2 removals by trees on *Non-Forest Land* (t CO_2/yr)
Net GHG Flux_{trees}	=	Average annual net GHG flux from trees on *Non-Forest Land* (t CO_2e/yr) (reflects the net balance of emissions of CO_2, CH_4, and N_2O and removals of CO_2)
$R_{treegain}$	=	Removals by trees on *Non-Forest Land* maintained and gained during the inventory (t C). This value is negative. From Step 8.
$E_{treeloss}$	=	Emissions from trees on *Non-Forest Land* lost during the inventory (t C). This value is positive. From Step 8.
$E_{trees\ non\text{-}CO2}$	=	CH_4 and N_2O emissions from biomass burning during prescribed fires that occurred on *Non-Forest Land* (t CO_2e). This value is positive. From Step 9.
T	=	Number of years in the inventory cycle. See Chapter 5.
$\frac{44}{12}$	=	Conversion factor to convert units of carbon to CO_2, based on the ratio of their molecular weights.

Source: All three equations adapted from IPCC 2006, vol. 4, chap. 2, equations 2.1 and 2.7.

Step 11: Calculate annual gross emissions, annual gross removals, and annual net GHG flux from *Forest Land* and trees on *Non-Forest Land*

The final calculation is to combine fluxes from *Forest Land* and *Non-Forest Land* (trees on *Non-Forest Land*) to obtain annual gross emissions, gross removals, and net GHG flux for the "Land" sub-sector during the inventory cycle (Equations 19, 20, and 21).

All *Forest Land* and trees on *Non-Forest Land* values are as described in Chapter 7, Step 10, and Chapter 8, Step 10.

Equation 19 Gross emissions from *Forest Land* and trees on *Non-Forest Land*
Equation 20 Gross removals by *Forest Land* and trees on *Non-Forest Land*
Equation 21 Net GHG flux from *Forest Land* and trees on *Non-Forest Land*

$$\textbf{19}\quad \textbf{Gross Emissions}_{\textbf{forest + trees}} = \text{Gross Emissions}_{\text{Forest Land}} + \text{Gross Emissions}_{\text{trees}}$$

$$\textbf{20}\quad \textbf{Gross Removals}_{\textbf{forest + trees}} = \text{Gross Removals}_{\text{Forest Land}} + \text{Gross Removals}_{\text{trees}}$$

$$\textbf{21}\quad \textbf{Net GHG Flux}_{\textbf{forest + trees}} = \text{Net GHG Flux}_{\text{Forest Land}} + \text{Net GHG Flux}_{\text{trees}}$$

Description

$\text{Gross Emissions}_{\text{forest + trees}}$	=	Average annual gross GHG emissions from *Forest Land* and trees on *Non-Forest Land* (t CO_2e/yr)
$\text{Gross Removals}_{\text{forest + trees}}$	=	Average annual gross CO_2 removals by *Forest Land* and trees on *Non-Forest Land* (t CO_2/yr)
$\text{Net GHG Flux}_{\text{forest + trees}}$	=	Average annual net GHG flux from *Forest Land* and trees on *Non-Forest Land* (t CO_2e/yr) (reflects the net balance of emissions of CO_2, CH_4, and N_2O and removals of CO_2)

PART IV

Reporting and setting goals

Once a community has calculated emissions from and removals by forests and trees (Part III), it shall report them within the "Land" sub-sector of its GHG inventory and may use the updated inventory to set or revise climate action targets. After incorporating "Land" GHG fluxes, communities may find themselves with carbon removals that change their perception of their overall GHG profile. Chapter 9 addresses how to transparently report on "Land" sub-sector GHG fluxes. Chapter 10 addresses how forests and trees can affect climate action goals. Whether and how a land sink is included in climate action goals is critical for evaluating their ambition.

9 Inventory reporting

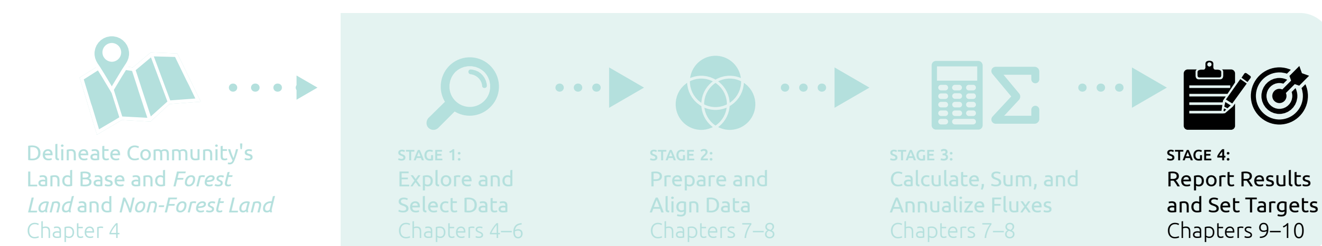
This chapter provides guidance on how communities should integrate the results for GHG fluxes related to forests and trees into the broader GHG inventory alongside other sectors, how to provide more detailed reports on GHG fluxes from forests and trees, when results may need to be recalculated or reformulated, and how to estimate uncertainty. Inventory reporting and target setting are shown in Figure 9.

9.1 Integrating forests and trees into the broader GHG inventory

National GHG inventories include both sources and sinks from land, and GHG fluxes are reported as a "net" value, meaning that both emissions (a positive value) and the carbon sink associated with forests and trees on *Non-Forest Land* (a negative value) are included. In contrast, many communities have not yet included forests and trees in their GHG inventories and have therefore not had to decide how to incorporate land-based GHG fluxes into their inventories. If a community has included the "Land" sub-sector in prior inventories, it may have included only emissions from deforestation but not yet considered the carbon sink provided by standing forests and trees on *Non-Forest Land*.

Once GHG emissions and CO_2 removals by forests and trees within a community's Scope 1 boundary are included in the inventory; however, further specificity is required regarding the definition of emissions and whether "Land"

Figure 9 **Reporting and target setting within the forest and tree GHG inventory workflow**



Source: Authors.

sub-sector removals are included. Communities that have calculated emissions from and removals by forests and trees shall report them within the “Land” sub-sector of their GHG inventory. Communities shall report gross emissions and net emissions across all sectors (including the “Land” sub-sector). Gross emissions include all relevant emissions within the GHG inventory boundary in all covered scopes (e.g., BASIC or BASIC+) and do not take into account CO_2 removals due to the “Land” sub-sector. Net emissions are gross emissions—including gross emissions from forests and trees—minus gross removals by forests and trees.[6]

The GPC requires reporting by sector, sub-sector, scope, and gas (GPC, Chapter 4). The GPC’s Tables 4.2 and 4.3 currently provide a single line for reporting for the “Land” sub-sector (V.2), under which *Forest Land* and trees on *Non-Forest Land* fall. However, reporting a single value for forests and trees, such as net GHG flux, masks important emission and removal dynamics. Therefore, Table 19 revises the GPC’s reporting Table 4.3 for all sectors, to include these “Land” sub-sector reporting requirements. For the “Land” sub-sector of AFOLU, communities shall report the following:

- Net emissions for the “Land” sub-sector in V.2, as shown in the GPC’s Table 4.3.
- Gross emissions and gross removals, reported separately (reporting categories V.2.1 and V.2.2, respectively). (GPC, Section 11.2, also requires this.) Other constituent fluxes, such as emissions from *Forest Land converted to Non-Forest Land* and removals by trees on *Non-Forest Land*, should be included in the “Explanatory Comments” column or disaggregated as additional rows in the reporting table.
- Whether any GHG fluxes are calculated but excluded from the inventory.
- The duration and start and end years of the inventory cycle over which GHG fluxes were calculated.
- The carbon pools and greenhouse gases included in emissions and removal calculations.
- Non-CO_2 emissions from fires separately from CO_2 fluxes, and converted to CO_2e using global warming potentials, if fires are present in the inventory. Non-CO_2 emissions are reported in V.3, “Emissions from Aggregate Sources and Non-CO_2 Emission Sources on Land within the City Boundary.”
- Notation keys when specific sources of emissions or removals are not included (GPC, Section 4.1). Notation keys are used to justify and explain exclusion of or partial accounting of fluxes (emissions or removals for “Land” sub-sector). Additional information on notation keys is provided in the GPC’s Chapter 2.

6. This supplement does not consider the role of carbon credits, and thus net removals are gross emissions minus “Land” sub-sector removals only.

Table 19 Integration of forest and tree GHG fluxes with other sectors of a community GHG inventory

GPC Ref. No	Scope	Greenhouse Gas Emissions Source (by Sector and Sub-sector)	Notation Keys	Gases (Tonnes)				Data Quality		Explanatory Comments
				CO_2	CH_4	N_2O	Total CO_2e	AD	EF	
I	1	Stationary Energy		8,200,000	500	500	8,200,000			
II	1	Transportation		4,900,000			4,900,000			
III	1	Waste		10,000			10,000			
IV	1	Industrial Processes and Product Uses		55,000			55,000			
V.1	1	Emissions from livestock within the community boundary		15,000			15,000			
V.2	1	Net GHG flux from *Forest Land* and trees on *Non-Forest Land* within the community boundary (sum of V.2.1 and V.2.2)		-62,000			-62,000	M	L	Annual average over 10 years (t CO_2e/yr) (2001–11) Gross emissions: 168,000 Gross removals: -230,000

Table 19 **Integration of forest and tree GHG fluxes with other sectors of a community GHG inventory, continued**

GPC Ref. No	Scope	Greenhouse Gas Emissions Source (by Sector and Sub-sector)	Notation Keys	Gases (Tonnes)				Data Quality		Explanatory Comments
				CO_2	CH_4	N_2O	Total CO_2e	AD	EF	
V.2.1	1	Emissions from *Forest Land* and trees on *Non-Forest Land* within the community boundary		168,000			168,000	H	M	Annual average over 10 years (t CO_2e/yr) (2001–11) C pools included: All C pools for *Forest Land* → *Forest Land* and land-use transitions involving *Forest Land*; aboveground and belowground biomass only for trees on *Non-Forest Land* GHG included: CO_2 Disaggregated reporting: *Forest Land* → *Settlements*: 35,000 *Forest Land* → *Grassland*: 4,000 *Forest Land* → *Other Land*: 7,000 *Forest Land* → *Forest Land* (CO_2): 2,000 Trees on *Non-Forest Land*: 120,000
V.2.2	1	Removals by *Forest Land* and trees on *Non-Forest Land* within the community boundary		-230,000			-230,000	M	L	Annual average over 10 years (t CO_2/yr) (2001–11) C pools included: All C pools for *Forest Land* → *Forest Land* and land-use transitions involving *Forest Land*; aboveground and belowground biomass only for trees on *Non-Forest Land* GHG included: CO_2 Disaggregated reporting: *Forest Land* → *Forest Land*: -75,000 *Non-Forest Land* → *Forest Land*: -10,000 Trees on *Non-Forest Land*: -145,000

Table 19 Integration of forest and tree GHG fluxes with other sectors of a community GHG inventory, continued

GPC Ref. No	Scope	Greenhouse Gas Emissions Source (by Sector and Sub-sector)	Notation Keys	Gases (Tonnes)				Data Quality		Explanatory Comments
				CO_2	CH_4	N_2O	Total CO_2e	AD	EF	
V.3	1	Emissions from aggregate sources and non-CO_2 emission sources on land within the community boundary			500	500	1,000	M	M	*Forest Land* → *Forest Land* (fires non-CO_2): 1,000 t CO_2e/yr
VI	3	Other Scope 3								
Gross emissions (emissions from all sectors)				13,348,000			13,349,000			Includes no V.2.2 gross removals
Net emissions (emissions from all sectors, minus removals from V.2)				13,118,000			13,119,000			Includes -230,000 t CO_2 V.2.2 gross removals

Notes: C = carbon; CO_2 = carbon dioxide; GHG= greenhouse gas; GPC = Global Protocol for Community-Scale Greenhouse Gas Inventories.
GPC reference number in column 1 is the same as GPC, Table 4.3, except that V.2 has been disaggregated into V.2.1 and V.2.2 for emissions and removals, respectively. Data for V.2 and V.3 use 2001–11 data from Table 20; data for all other rows are hypothetical and provided for completeness. Columns that are not relevant to this supplement, such as other gases and biogenic CO_2, are not shown here. Gray rows are carried over from the standard reporting table (GPC, Table 4.3); orange rows are additions to the standard GPC table based on this supplement. Other Scope 3 emissions, which include the Stationary Energy, Transportation, Industrial Process and Product Use, and Agriculture, Forestry, and Other Land Uses sectors, will be addressed in future GPC guidance.

9.2 Reporting and displaying results from the inventory

The *Forest Land* and trees on *Non-Forest Land* methods described in this supplement can produce very detailed results that exceed what would be included for this sub-sector in standard GPC reporting (covered in the previous section). Beyond the inventory-wide reporting of Table 19, communities may wish to report GHG fluxes at various levels of aggregation or for specific subcategories for different audiences, as well as provide different amounts of contextual information, such as the land-use change matrix, areas disturbed, or area of trees on *Non-Forest Land*. Table 20 shows one possible configuration for reporting more detailed GHG fluxes from forests and trees.

GHG inventories are commonly reported in a tabular format. However, displaying results in a graphical format is particularly helpful for showing the opposing emissions and removals in a land inventory. For example, waterfall charts can help show how individual components of the land inventory influence the total net emissions or removals (Figure 10). Graphs are also useful where forests are a large sink or when a community subcategorizes its land to show emissions and/or removals occurring in different forest- or land-ownership types.

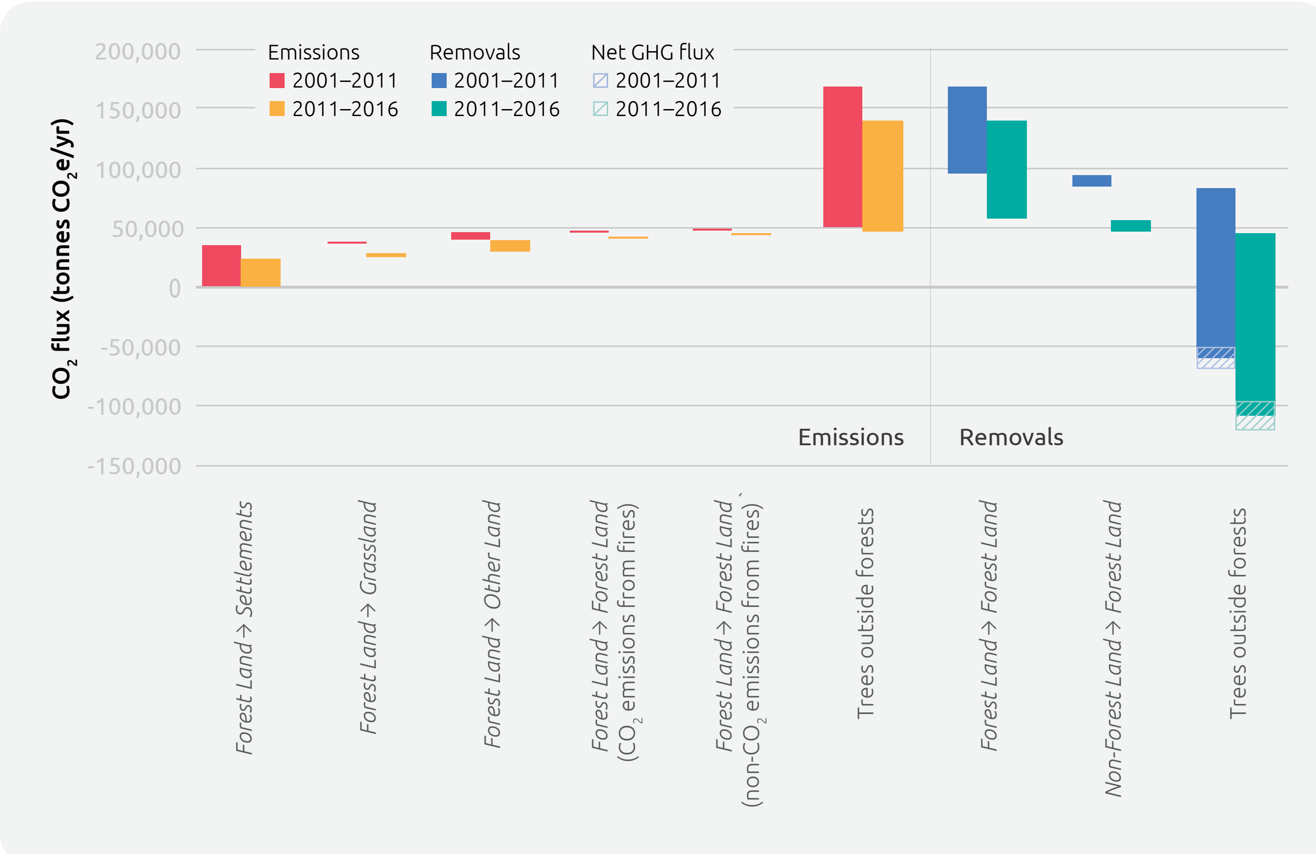
Communities may also be interested in the degree to which results change across consecutive inventory cycles. When communities have conducted multiple inventories with the same methods (e.g., 2001–11 and 2011–16), they can be compared to assess changes in fluxes from forests and trees over time (Table 20). Annualizing GHG fluxes allows comparison across inventory cycles even when the data update cycles include different numbers of years (Chapter 5).

Table 20 ***Forest Land*** **and trees on** ***Non-Forest Land*** **GHG fluxes for a community over two inventory cycles**

Reporting Category	Carbon Pools Included	2001–2011	2011–2016	Percent Change
EMISSIONS (T CO_2E/YR)				
Forest Land → *Settlements*	All ecosystem pools	35,000	25,000	-29
Forest Land → *Grassland*	All ecosystem pools	4,000	5,000	25
Forest Land → *Other Land*	All ecosystem pools	7,000	10,000	43
Forest Land → *Forest Land* (CO_2 emissions from fires)	All ecosystem pools	2,000	4,000	100
Forest Land → *Forest Land* (non-CO_2 emissions from fires)	All ecosystem pools	1,000	2,000	100
TOTAL FORESTS	**N/A**	**49,000**	**46,000**	**-6**
Trees on *Non-Forest Land*	Aboveground + belowground biomass	120,000	95,000	-21
TOTAL FORESTS + TREES	**N/A**	**169,000**	**141,000**	**-17**
REMOVALS (T CO_2/YR)				
Forest Land → *Forest Land*	Aboveground + belowground biomass	-75,000	-83,000	-11
Non-Forest Land → *Forest Land*	Aboveground + belowground biomass	-10,000	-12,000	-20
TOTAL FORESTS	**N/A**	**-85,000**	**-95,000**	**-12**
Trees on *Non-Forest Land*	Aboveground + belowground biomass	-145,000	-155,000	-7
TOTAL FORESTS + TREES	**N/A**	**-230,000**	**-250,000**	**-9**
NET FLUX (T CO_2E/YR)				
TOTAL FORESTS + TREES	**N/A**	**-61,000**	**-109,000**	**-79**

Note: In the 2001–11 and 2011–16 columns, positive values are emissions and negative values are removals. In the "Percent Change" column, positive values (orange cells) mean increasing emissions or decreasing removals and negative values (blue cells) mean decreasing emissions or increasing removals. Net removals increased from -61,000 t CO_2e/year to -109,000 t CO_2e/year due to a decrease in emissions and an increase in removals for forests and trees.

Figure 10 **Two consecutive inventories displayed as a waterfall chart**



Note: This waterfall chart shows how individual subcategories of the inventory influence the net total emissions (red and orange) and removals (blue and teal) from forests and trees over time. Data are from Table 20. Net removals increased over the two inventory periods due to a decrease in emissions and an increase in removals for *Forest Land* and trees on *Non-Forest Land*.
Source: Authors.

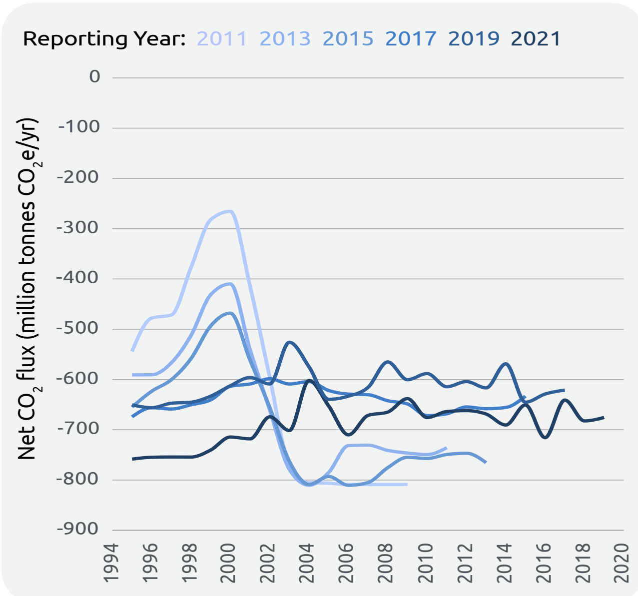
9.3 The inventory base cycle and its recalculation over time

While other sectors have base years against which changes in emissions are compared, it is common for "Land" sub-sector GHG fluxes to be estimated over a longer base cycle instead (Chapter 5). Ideally, the base cycle aligns with the base year for other sectors (Table 9).

As with other sectors, consistency across inventory cycles is necessary for calculating trends over time. Thus, methods used to calculate GHG fluxes in the base cycle shall be the same as the methods used to calculate fluxes in subsequent inventories. This means that if new methods or data are used to calculate fluxes for a new inventory, previous inventories shall be recalculated using the same methods. The GPC's Chapter 11 provides guidance on triggers for recalculating previous inventories.

It is very common for communities (and countries) to retroactively update inventories as new information becomes available. As in other sectors, such as Stationary Energy, new data and information can change the results substantially (Figure 11). Changes in land-related GHG flux estimates during recent inventories may be particularly common, but they are difficult to harmonize with previous inventories when these are due to changes in available activity data. Land-use and land-cover data sources change rapidly due to evolving technology and the underlying

Figure 11 **Changes in net forest GHG flux estimates for the United States vary by reporting year**



Notes: CO_2 = carbon dioxide; GHG = greenhouse gas.

Fluxes for *Forest Land remaining Forest Land* only. Each year, the entire time series of the U.S. inventory is recalculated back to 1990 to incorporate new and evolving information as the field of learning progresses. This can result in large changes to the estimates for *Forest Land remaining Forest Land* due to recalculation procedures. The last year covered by the inventory is about two years behind the reporting year.

Source: EPA (n.d.).

science, and data available for the most recent inventory may not have been available for previous inventories because of limitations in remote sensing or data processing. This can happen, for example, if previous inventories used satellite imagery with coarser spatial resolution to detect forest change but the current inventory uses higher-resolution imagery. Emission and carbon gain factors can also change as values are updated and refined with new data, but these can usually be applied retroactively without concern.

If possible, previous inventories should be recalculated with data used in the most recent inventory. When this is not possible, communities should decide whether to continue to use the old data for continuity of record (potentially sacrificing the improvements in the inventory to be obtained from new, higher-quality data) or whether to attempt to reconcile the older and newer data sources to create a semicontinuous record, such as by establishing a relationship between the new and old data sources and then backcasting the new data. When communities take the latter approach, they must consider whether the methods used to harmonize two or more data sources allow for meaningful comparison across time. One important aspect of ensuring comparability across inventory cycles is that the area of land in the land-use change matrices shall be the same across all inventory periods; backcasting new activity data to previous inventory periods can result in an altered inventory area that must be harmonized. If backcasting of more recent data is done, this shall be explained in all inventories in which this occurs.

9.4 Estimating uncertainty

Estimating uncertainty for land-related GHGs is complex because there are many potential sources of error. Land use and change maps can contain classification errors. Emission and/or carbon gain factors also have uncertainty, particularly if these factors are derived from sparse data over relatively small and/or heterogeneous land areas. In addition to these sources of uncertainty, there may be significant bias in estimates of factors. For example, if an emission factor associated with a harvesting disturbance is based on a regional average, the true value for the community area within the region may be higher or lower than the regional average value used.

Communities shall take the approach for managing uncertainty for forests and trees that is described in the GPC's Section 5.6, in which activity data and emission and carbon gain factor quality is assessed as high, medium, or low. The evaluation is based on the degree to which data used reflect the geographical location of where they are applied, and whether data have been obtained from reliable and verifiable sources (Table 21). Given recent advances in the use of satellite data to map forest area and tree-canopy change, the quality of activity data for a community's land GHG inventory may be high, while the quality of the emission or carbon gain factors used to convert the activity data into estimates of GHG fluxes may be medium or low.

Table 21 **Data quality assessment**

Data Quality	Activity Data	Emission or Carbon Gain Factor
High (H)	Detailed activity data	Specific emission / carbon gain factors
Medium (M)	Modeled activity data using robust assumptions	More general emission / carbon gain factors
Low (L)	Highly modeled or uncertain activity data	IPCC default emission / carbon gain factors

A qualitative uncertainty analysis can help communities determine which inputs to the inventory are important to improve in future cycles. Conducting a GHG inventory for a community's lands and updating only the activity data through time can provide sufficient information about the relative magnitude of the sector's contribution to atmospheric GHGs, how it is changing over time, and its potential impact on climate change mitigation. In other words, high confidence in relative changes in or directionality of the "Land" sub-sector's GHG flux estimates over time may be more important for informing climate action than the absolute magnitude of the fluxes. As stated in Chapter 1, the GHG flux estimates developed for community-scale inventories are designed to inform local policies and climate action plans, not to generate or sell carbon credits.

In addition to using the above method for evaluating data quality, communities can combine (or "propagate") uncertainty with specific formulas to develop a quantitative estimate (such as standard deviation). The IPCC Guidelines (IPCC 2006, 2019b) provide a simplified method.

Communities should consider the sources of uncertainty and apply commonsense 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 carbon gain factors that represent conditions most similar to those in the community. When communities use national land-cover data, a customized accuracy assessment can be implemented to improve the local area estimates (activity data) and calculate a confidence interval around the local land-cover change assessment (see Olofsson et al. 2014). Other sources of uncertainty, such as uncertainty of the models used to estimate carbon density or carbon gain factors, may be more challenging to quantify.

10 Incorporating forest and tree GHG fluxes into climate action goals

Folding CO_2 removals into an existing climate action goal may change, and potentially complicate, the way communities set climate action goals. On the one hand, including an existing sink in the inventory and related mitigation goals could result in the perverse outcome that communities perceive less need to reduce emissions in other sectors. On the other hand, excluding an existing sink from the inventory and related mitigation goals paints an incomplete picture of a community's GHG fluxes. Excluding removals could also lead to perverse outcomes of communities failing to consider the climate benefits that standing forests and trees provide and disregarding significant and viable land-related mitigation solutions.

Communities face two main challenges when including removals by forests and trees in climate goals.

First, communities may have already set their target on the basis of gross emissions, and therefore may be unsure about whether this target should be revised to be based instead on net emissions (i.e., including the land sink). This is particularly relevant for communities that set a "net-zero" target without considering how Scope 1 removals factor into this goal.

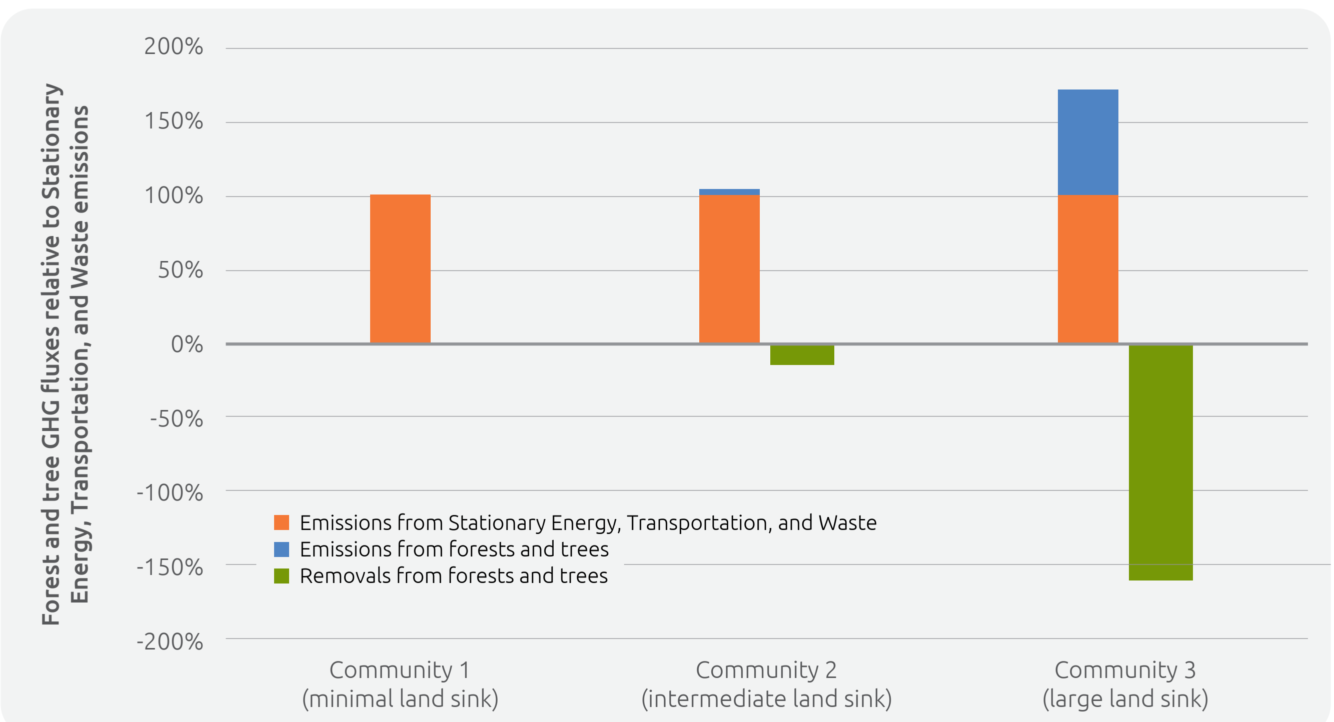
Second, when introducing removals by forests and trees in climate targets, communities have very different starting points regarding the absolute and relative magnitude of their existing sink, depending on how much forest and tree cover is present within their geographic boundaries. Therefore, the way communities incorporate the "Land" sub-sector into their climate targets may differ depending on the size of the sink relative to emissions from other sectors (Figure 12). Communities exist along a continuum of the size of the land sink relative to gross emissions:

- **Minimal land sink:** For highly urbanized communities with intensive emissions and very little forest and open space, almost the entire GHG inventory is likely to be emissions from the Stationary Energy, Transportation, and Waste sectors (community 1 in Figure 12). While Scope 1 CO_2 removals by forests and trees may be present and significant in an absolute sense, they may be relatively insignificant when compared to high emissions across other sectors. In these cases, the inventory's net emissions (including the land sink) will be nearly identical to gross emissions.

- **Large land sink:** In contrast, heavily forested communities may have significant Scope 1 CO_2 removals in their "Land" sub-sector relative to emissions from other sectors, particularly if the community does not have high emissions from other sectors, including AFOLU sub-sectors (e.g., Livestock) (community 3 in Figure 12). In these cases, after the land sink is included in the inventory, net emissions (including land sink) may be significantly lower than gross emissions. Net emissions may even approach zero, or there may be a net sink.
- **Intermediate land sink:** Most communities will fall somewhere in between these two extremes, where the community boundary includes emissions-intensive cities but also significant areas of *Forest Land* and trees on *Non-Forest Land* that remove carbon from the atmosphere (community 2 in Figure 12).

Both the type of GHG target that has been set by the community (Box 11) and the community's starting point in terms of removals by forests and trees relative to emissions from all other sectors (Figure 12) should be considered when determining how GHG fluxes from forests and trees are incorporated into a community's target. While removals are always reported separately in the inventory, the way carbon sinks associated with forests and trees are incorporated into a climate target will be different for each community depending on its starting point, especially if a target has already been set based only on gross emissions from the Stationary Energy, Transportation, and Waste sectors.

Figure 12 **Different communities have different starting points with respect to the size of their existing carbon sink from forests and trees**



Notes: GHG = greenhouse gas.
100% represents the emissions from the Stationary Energy, Transportation, and Waste sectors combined during an inventory cycle. All other bars are relative to that.
Source: Authors.

The GPC states that communities "must set a carbon neutrality target separately and along with a GHG emission reduction target and the two must be viewed as complementary since not specifying a GHG reduction target could lead to reliance on high rates of GHG removals, or offsets if used, to balance high rates of emissions" (GPC, Section 11.1). Setting separate targets for emissions and removals increases clarity and enables communities to develop parallel mitigation strategies for reducing emissions and increasing removals. This, in turn, should increase opportunities and ambition for mitigation as compared to focusing solely on one or the other.

However, for communities with large populations and intensive emissions from the Stationary Energy, Transportation, and Waste sectors (community 1 in Figure 12), it may be most straightforward and pragmatic to include a sink associated with forests and trees alongside other sectors when developing and communicating a climate target. In these cases, net emissions (with land sink) will be almost identical to gross emissions. Getting to net zero—or to a relative target—will already be very difficult for these types of communities, so the sink associated with their forests and trees can help cities travel the "last mile" of climate neutrality or reach other ambitious targets. To neutralize their hardest-to-reduce emissions, these communities may also consider the purchase of limited amounts of high-quality carbon offsets as part of reaching a carbon-neutral target.

For communities with larger forest areas and/or low populations (communities 2 and 3 in Figure 12) with a current land sink that counterbalances 5 percent or more of current gross emissions, communities should have a separate mitigation goal (or goals) for AFOLU and/or related specifically to the "Land" sub-sector. These targets may involve increasing the sink and/or reducing emissions from deforestation and/or loss of tree canopy on *Non-Forest Land*.

Communities that set separate land sink targets may develop targets that account for all lands collectively as well as for individual land-use classes separately to focus on specific categories or interventions. For example, communities may design a base-year target for the "Land" sub-sector of increasing the sink by 10 percent by 2030 relative to 2005, while also designing additional mitigation goals that can be tracked and accounted within specific land-use classes, such as increasing net carbon sequestration within the *Settlements remaining Settlements* class by increasing urban tree canopy from x percent in 2005 to y percent by 2030, or reducing emissions from deforestation (*Forest Land converted to Non-Forest Land*) by z percent by 2030 relative to a 2015–20 baseline. Communities may also wish to separate their GHG targets into GHG fluxes occurring within lands that the community has direct management control over versus those occurring within areas of federal or state lands, protected areas, or

other lands where the community has little management control. This will avoid perceptions that the community is claiming credit for a sink it does not manage.

The ways a land sink is incorporated into a climate target can be characterized however makes most sense for the community. Regardless, when incorporating carbon removals by forests and trees into a climate goal, the mitigation effort should be transparent so that the degree of ambition in the target is clear to all stakeholders. A monitoring, evaluation, reporting, and learning framework helps communities track and review results of the inventory over time and assess progress against their targets. A well-functioning framework improves the accountability and transparency of GHG reporting and embraces learning and reflection, so that progress toward goals can be iterative and based on experience of what does and does not work, allowing ambition to increase over time.

Box 11 Types of climate goals

Just as different countries set their nationally determined contribution targets under the Paris Agreement in various ways, communities can set their climate goals and/or mitigation goals in multiple ways. In general, there are four types of goals: base-year emissions goals, base-year intensity goals, baseline scenario goals, and fixed-level goals. Chapter 11 of the Global Protocol for Community-Scale Greenhouse Gas Inventories (WRI et al. 2021) and Chapter 6 of the GHG Protocol's "Mitigation Goal Standard" (WRI 2014) describe these goal types in detail and offer guidance for designing subnational mitigation goals. We summarize them as follows for reference:

- **Base-year emissions goals** aim to achieve a specified percentage of reduction in emissions from a base year by a target year. For example, a community may set a target of reducing economy-wide emissions by 30 percent below 2005 levels by 2030. Base-year emissions targets are a common way that countries express their nationally determined contributions under the Paris Agreement.
- **Base-year intensity goals** are similar to base-year emissions goals, except that they correspond to an absolute reduction in emissions intensity (i.e., emissions per unit output) rather than an absolute reduction in total emissions.
- **Baseline scenario goals** involve tracking emission reductions not in absolute terms but relative to a forward-looking baseline scenario, or a prediction of emissions that are most likely to occur in the future in the absence of activities taken by a community to meet a mitigation goal.
- **Fixed-level goals** are an increasingly common type of target set by communities to reach carbon (or climate) neutrality by a certain date. Fixed-level goals have been set by many cities in response to the Paris Agreement, which suggested that the world needs to be carbon neutral by the second half of the century. Increasingly, more and more cities and other subnational actors are taking on this "net zero" goal. At present, 11,000 cities around the world have pledged to become carbon neutral by 2050 (Steer and Hanson 2021). In contrast to other types of targets, a fixed-level goal does not require a reference to a historical base-year or baseline scenario. Rather, it states that emissions and removals together will be an absolute emissions level, often zero, by a certain date.

Appendices

Appendix A
Inventory requirements

This supplement's requirements for communities that include *Forest Land* and trees on *Non-Forest Land* (collectively, forests and trees) in their greenhouse gas inventory are summarized below.

General:

- GHG inventories that include the "Land" sub-sector of AFOLU shall include all forest-related land-use transitions (i.e., deforestation and afforestation or reforestation) and *Forest Land remaining Forest Land*. (Chapter 7)
- GHG inventories that include the "Land" sub-sector of AFOLU shall include trees on *Non-Forest Land*. (Chapter 8)
- Communities that have calculated emissions from and removals by forests and trees shall report them within the "Land" sub-sector of their GHG inventory. (Section 9.1)
- In addition to net GHG flux, GHG emissions and CO_2 removals shall be reported separately in GHG inventories that include forests and trees. (Section 9.1)

GHG accounting boundary requirements:

- If the community boundary changes prior to a follow-up inventory (e.g., territory annexed), previous inventories shall be recalculated using the new land base. (Section 4.1)
- Areas outside the boundary that the community owns, manages, or influences may be included in the inventory, but they shall be reported separately as Other Scope 3. This includes areas directly influenced by the community's planning decisions. (Section 4.1)
- Areas inside the GHG accounting boundary where local land-use policies do not apply, such as national parks or areas managed by carbon project developers, shall be included in the community boundary, but their fluxes may be tracked and reported separately to provide context for the community's inventory. (Section 4.1)
- Regardless of what land-use classification is employed, the categories shall exhaustively and exclusively divide the community's land. (Section 4.2)
- Where a portion of community land is designated as unmanaged and excluded from the inventory, justification shall be provided on the methods used to delineate the unmanaged land and geospatial boundaries shall be provided in documentation. (Box 5)
- The reasons for selecting the inventory years included in an inventory cycle for *Forest Land* and trees on *Non-Forest Land* shall be documented, including reasons for different monitoring period lengths, if applicable. (Chapters 7 and 8, Step 3)

Land representation requirements:

- Once a community's land area has been delineated for the inventory, it shall be classified into subcategories according to the IPCC's six main land-use categories: *Forest Land*, *Cropland*, *Grassland*, *Wetlands*, *Settlements*, and *Other Land*. (Section 4.2)
- The same land-use definitions shall be applied consistently throughout the inventory so that changes in definitions do not appear in the inventory as land-use changes, as could occur, for example, when comparing different land-cover or land-use maps produced with different classification methods for different years. If land-use definitions are changed in a follow-up inventory, the changes shall be retroactively applied to previous inventories and the inventories recalculated. (Section 4.2)
- To comply with GPC reporting guidelines, community inventories shall apply land-use definitions, not land-cover ones. (Section 4.2)

Calculation requirements:

- Communities shall determine whether there were substantial changes in conditions within *Forest Land remaining Forest Land* that need to be included in the inventory, such as forest disturbances (fires, disease outbreaks, etc.) or forest management activities (harvesting, thinning, etc.) which would be associated with emissions. (Chapter 7, Step 2)
- Every *Forest Land* and trees on *Non-Forest Land* subcategory for which there are activity data shall have a corresponding emission and/or carbon gain factor, although the factors do not need to be unique to every subcategory (i.e., subcategories can share the same

emission and/or carbon gain factors). (Chapters 7 and 8, Step 5)

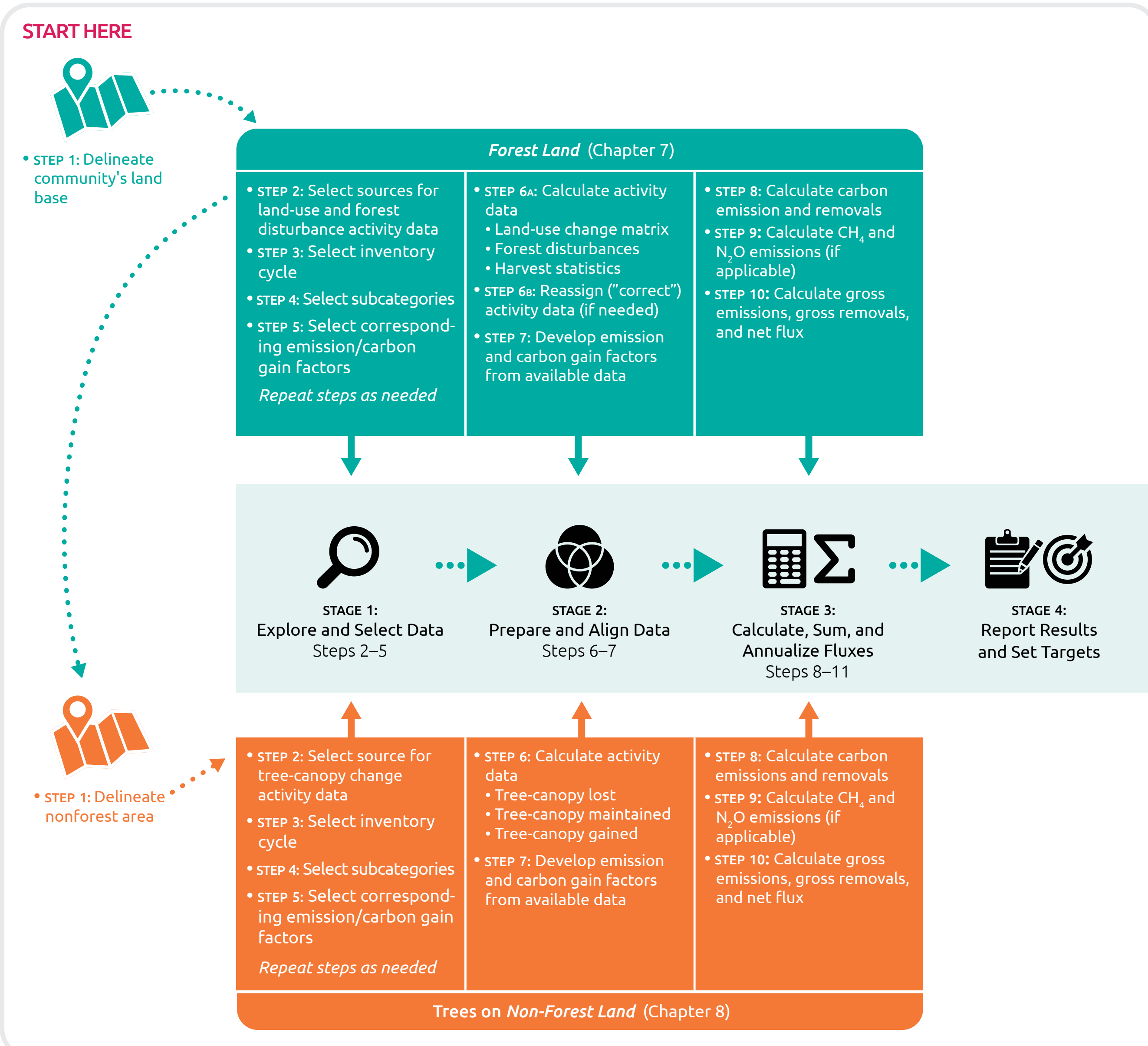
- If forest management activities occurred within the community during the inventory, data on harvest volumes for timber or fuelwood shall be used to estimate emissions for these types of disturbances, since not all harvest activity may be detected as a forest disturbance in satellite-based land-cover change-monitoring approaches (Chapter 7, Step 6a). With this approach, the area of forest disturbance from other disturbance data sources (e.g., aerial imagery) and attributed to harvest or fuelwood collection areas shall be ignored to avoid double-counting emissions from wood harvest (Chapter 7, Step 3).
- All investigation into and decisions about corrections applied to the land-use change matrix shall be documented and justified. (Chapter 7, Step 6b)
- Methods used to calculate GHG fluxes in the base cycle shall be the same as the methods used to calculate fluxes in subsequent inventories. This means that if new methods or data are used to calculate fluxes for a new inventory, previous inventories shall be recalculated to use the same methods. (Section 9.3)
- To ensure comparability across inventory periods, the area of land in the land-use change matrices shall be the same across all inventory periods; backcasting new activity data to previous inventory periods can result in an altered inventory area that must be harmonized. If backcasting of more recent data is done, this shall be explained in all inventories in which this occurs. (Section 9.3)

Reporting requirements:

- For the "Land" sub-sector of AFOLU, communities shall report the following (Section 9.1):
  - Net emissions for the "Land" sub-sector in V.2, as shown in the GPC's Table 4.3.
  - Gross emissions and gross removals separately (reporting categories V.2.1 and V.2.2, respectively).
  - Whether any GHG fluxes were calculated but excluded from the inventory.
  - The duration and start and end years of the inventory cycle over which GHG fluxes were calculated.
  - The carbon pools and greenhouse gases included in emissions and removals.
  - Non-CO_2 emissions from fires separately from CO_2 fluxes, and converted to CO_2e using global warming potentials, if fires are present in the inventory. Non-CO_2 emissions are reported in V.3, "Emissions from Aggregate Sources and Non-CO_2 Emission Sources on Land within the City Boundary."
  - Notation keys when specific sources of emissions or removals are not included. (GPC, Section 4.1)
- Inventory totals shall be reported in both gross and net terms, where gross emissions include GHG emissions across all sectors and net GHG emissions are gross emissions less any CO_2 removals. (Section 9.1)
- Where applicable, communities shall convert total GHG fluxes from their forests and trees as calculated over a multiyear inventory into an annual average (continuous 12-month period) based on the number of years covered by the inventory. (Chapter 5)
- The selected approach for including "Land" sub-sector removals shall be noted in inventory reporting. (Section 9.1)
- If no or minimal fires occurred during the inventory period, their absence from the inventory shall be reported with the appropriate notation key. (Chapter 7, Step 9)
- Communities shall report uncertainty as described in the GPC's Section 5.6, in which activity data and emission and carbon gain factor quality is assessed as high, medium, or low. (Section 9.4)
- In cases where emission reductions and removals originating in the community boundary are sold on the voluntary market, these shall be reported separately. Communities should track lands accounted under different voluntary crediting systems separately to provide context to the inventory. It is possible that GHG estimation results from the community inventory for these project areas will differ from the baseline and monitoring results generated for crediting purposes, due to differences in the data and quantification methods applied. Regardless, communities shall report any credits bought or sold separately from their inventory (GPC, Chapter 11). (Box 6)

Appendix B
Full forest and tree GHG inventory workflow

Figure B1 **Steps for completing a GHG inventory for forests and trees**



Notes: CH_4 = methane; N_2O = nitrous oxide. Parts of this figure are shown in Figures 3, 6, 7, and 9.
Source: Authors.

Appendix C
Default fire emission and combustion factors

Table C1 Fire emission factors (EF) for methane (CH_4) and nitrous oxide (N_2O) (g/kg dry matter)

Category	EF_{CH4}	EF_{N2O}
Savanna and grassland	2.3	0.21
Agricultural residues	2.7	0.07
Tropical forest	6.8	0.20
Nontropical forest	4.7	0.26
Biofuel burning	6.1	0.06

Source: Adapted from IPCC (2019b, vol. 4, chap. 2, table 2.5). For use in Chapter 7, Step 9.

Table C2 Fire combustion factors (proportion of prefire fuel biomass consumed, Cf)

Vegetation type	Subcategory	Mean
Primary tropical forest (slash and burn)	Primary tropical forest	0.32
	Primary open tropical forest	0.45
	Primary tropical moist forest	0.50
	Primary tropical dry forest	No data
ALL PRIMARY TROPICAL FORESTS		**0.36**
Secondary tropical forest (slash and burn)	Young secondary tropical forest (3–5 yrs.)	0.46
	Intermediate secondary tropical forest (6–10 yrs.)	0.67
	Advanced secondary tropical forest (14–17 yrs.)	0.50
ALL SECONDARY TROPICAL FORESTS		**0.55**
ALL TERTIARY TROPICAL FORESTS		**0.59**

Table C2 **Fire combustion factors (proportion of prefire fuel biomass consumed, Cf), continued**

Vegetation type	Subcategory	Mean
Boreal forest	Wildfire (general)	0.40
	Crown fire	0.43
	Surface fire	0.15
	Post logging slash burn	0.33
	Land clearing fire	0.59
ALL BOREAL FORESTS		**0.34**
Eucalyptus forests	Wildfire	No data
	Prescribed fire (surface)	0.61
	Post logging slash burn	0.68
	Felled and burned (land-clearing fire)	0.49
ALL EUCALYPTUS FORESTS		**0.63**
Other temperate forests	Post logging slash burn	0.62
	Felled and burned (land-clearing fire)	0.51
ALL "OTHER" TEMPERATE FORESTS		**0.45**
Shrubland	Shrubland (general)	0.95
	Calluna heath	0.71
	Fynbos	0.61
ALL SHRUBLANDS		**0.72**
Savanna woodlands (early dry season burns)	Savanna woodland	0.22
	Savanna parkland	0.73
	Other savanna woodlands	0.37
ALL SAVANNA WOODLANDS (EARLY DRY SEASON BURNS)		**0.40**

Table C2 **Fire combustion factors (proportion of prefire fuel biomass consumed, Cf), continued**

Vegetation type	Subcategory	Mean
Savanna woodlands (mid/late dry season burns)	Savanna woodland	0.72
	Savanna parkland	0.82
	Tropical savanna	0.73
	Other savanna woodlands	0.68
ALL SAVANNA WOODLANDS (MID/LATE DRY SEASON BURNS)		**0.74**
Savanna grasslands/pastures (early dry season burns)	Tropical/subtropical grassland	0.74
	Grassland	No data
SAVANNA GRASSLANDS/PASTURES (EARLY DRY SEASON BURNS)		**0.74**
Savanna grasslands/pastures (mid/late dry season burns	Tropical/subtropical grassland	0.92
	Tropical pasture	0.35
	Savanna	0.86
ALL SAVANNA GRASSLANDS/PASTURES (MID/LATE DRY SEASON BURNS)		**0.77**
Other vegetation types	Peatland	0.50
	Tropical wetlands	0.70
Agricultural residues (postharvest field burning)	Wheat residues	0.90
	Maize residues	0.80
	Rice residues	0.80
	Sugarcane	0.80
	Other crops	0.85

Source: Adapted from IPCC (2019b, vol. 4, chap. 2, table 2.5). For use in Chapter 7, Step 9.

Appendix D
Example of a forest and tree GHG inventory (downloadable spreadsheet)

Please see www.wri.org/research/global-protocol-community-scale-greenhouse-gas-inventories-guidance-forests-trees.

Abbreviations

AFOLU	Agriculture, forestry, and other land uses
AGP	Active growing period
BCEF	Biomass conversion and expansion factor
C	Carbon
CH_4	Methane
CONAFOR	National Forestry Commission of Mexico (Comisión Nacional Forestal)
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
EF	Emission factor
F	*Forest Land*
GF	Carbon gain factor
GHG	Greenhouse gas
GHGP	Greenhouse Gas Protocol
GIS	Geographic information system
GPC	Global Protocol for Community-Scale Greenhouse Gas Inventories
GWP	Global warming potential
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and product use
m^3	Cubic meter
NBS	Nature-based solutions
NDC	Nationally determined contribution
NF	*Non-Forest Land*
N_2O	Nitrous oxide
SEDEMA	Secretaría del Medio Ambiente (Mexico City Department of Environment)
t	Metric tonne
UNFCCC	UN Framework Convention on Climate Change
USCP	U.S. Community Protocol

Glossary

Activity data* A quantitative measure of a level of activity that results in GHG emissions. Activity data are multiplied by an emission factor to derive the GHG emissions associated with a process or an operation. In the context of forests and trees, activity data include land-use change, *Forest Land* disturbances, and loss, gain, and maintenance of trees on *Non-Forest Land*. Examples of activity data for *Forest Land* and trees on *Non-Forest Land* include the area of *Forest Land* lost or burned and the area or number of trees on *Non-Forest Land* gained during an inventory cycle.

BASIC* An inventory reporting level that includes all Scope 1 (territorial) sources except from energy generation, imported waste, industrial processes and product use (IPPU), and agriculture, forestry, and other land uses (AFOLU), as well as all Scope 2 sources.

BASIC+* An inventory reporting level that covers all BASIC sources, plus Scope 1 (territorial) AFOLU and IPPU, and Scope 3 in the Stationary Energy and Transportation sectors.

biomass[+] Organic material both aboveground and belowground, and both living and dead (trees, crops, grasses, tree litter, roots, etc.). Biomass includes the pool definition for above- and belowground biomass.

carbon credit* A carbon credit represents a metric tonne of CO_2 equivalent that is avoided or sequestered outside the GHG accounting boundary, which can be used to compensate for a tonne of residual GHG emissions occurring within the accounting boundary.

carbon density The quantity of carbon stored in a pool in a given area at a given time (tonnes C/ha).

carbon gain factor The amount of carbon accumulated by vegetation per unit area of land use during a specified time, usually one year.

community Geographically discernible subnational entities, such as towns, cities, provinces, districts, townships, wards, and neighborhoods. The term is used to indicate all levels of subnational jurisdiction as well as local government and legal entities of public administration.

CO_2 equivalent* The universal unit of measurement to indicate the global warming potential (GWP) of each GHG, expressed in terms of the GWP of one unit of carbon dioxide. The term is used to evaluate the climate impact of releasing (or avoiding releasing) different greenhouse gases on a common basis.

carbon pool Reservoir in which carbon is stored. For this supplement, the relevant pools are aboveground biomass, belowground biomass (roots), deadwood, litter, and soil organic carbon.

carbon stock[+] The quantity of carbon stored in a pool at a given time (tonnes C).

emission* The release of greenhouse gases into the atmosphere.

emission factor	A factor that converts activity data into GHG emissions data. For forests and trees, the amount of carbon emitted by each carbon pool per unit of land area (e.g., tonnes CO_2e emitted per hectare of *Forest Land converted to Non-Forest Land*, tonnes CO_2e emitted per hectare of *Forest Land* burned, tonnes CO_2e emitted per hectare of canopy of trees on *Non-Forest Land*).
forests and trees	Collectively, *Forest Land* and trees on *Non-Forest Land*.
Forest Land	All land with woody vegetation consistent with thresholds used to define *Forest Land* in a national inventory.
gain-loss method	Net CO_2 fluxes (changes in C stocks) are estimated during an inventory cycle as the product of activity data and emission or carbon gain factors.
geographic boundary*	A geographic boundary that identifies the spatial dimensions of the inventory's assessment boundary. This geographic boundary defines the physical perimeter separating in-boundary emissions from out-of-boundary and transboundary emissions.
global warming potential*	A factor describing the radiative forcing impact (degree of harm to the atmosphere) of one unit of a given GHG relative to one unit of CO_2.
greenhouse gases (GHGs)*	For the purposes of the GPC, GHGs are the seven gases covered by the UNFCCC: carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); sulfur hexafluoride (SF_6); and nitrogen trifluoride (NF_3). Only CO_2, CH_4, and N_2O are relevant to this supplement.
greenhouse gas (GHG) flux+	Transfer of GHGs from one pool to another (tonnes C/ha/yr). Composed of GHG emissions and CO_2 removals.
greenhouse gas inventory*	A quantified list of a community's GHG emissions and sources.
gross emissions*	Gross emissions include all relevant emissions within the GHG inventory boundary in all covered scopes (e.g., BASIC or BASIC+), and do not take into account any CO_2 removals due to the "Land" sub-sector.
gross removals	Gross removals include all removals within a GHG accounting boundary in all covered scopes (e.g., BASIC or BASIC+), and do not take into account any GHG emissions.
inventory boundary*	The inventory boundary of a GHG inventory identifies the gases, emission sources, geographic area, and time span covered by the GHG inventory.
inventory cycle	The years included in a "Land" sub-sector GHG inventory.
land use+	The type of activity being carried out on a unit of land.
land cover+	What is physically covering the earth's surface.
net emissions/net flux*	Gross emissions—including gross emissions from forests and trees—minus gross removals by forests and trees.
Non-Forest Land	All area within *Cropland*, *Grassland*, *Settlements*, *Wetlands*, and *Other Land*.
reporting year*	The year for which emissions are reported.

Scope 1 emissions*	GHG emissions from sources located within the city boundary.
Scope 2 emissions*	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary.
Scope 3 emissions*	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.
sink+	Any process, activity, or mechanism that removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas from the atmosphere. Notation in reporting is the negative (-) sign.
source+	Any process or activity that releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere. Notation in reporting is the positive (+) sign.
stock-change (stock-difference) method	Net CO_2 fluxes (changes in C stocks) are inferred from the difference in carbon stocks during repeated measurements of C stocks at different times across a network of inventory plots.
subcategory (stratum)	Division of a community's land base into additional classes beyond land use (e.g., ownership, forest type).
supplement	Global Protocol for Community-Scale Greenhouse Gas Inventories Supplemental Guidance for Forests and Trees
tonne	Metric ton (1 megagram, 1 million grams).
trees on *Non-Forest Land*	Trees present in land uses besides *Forest Land*. Also referred to as "trees outside forests."
trees outside forests	Trees present in land uses besides *Forest Land*. Also referred to as "trees on *Non-Forest Land*."

Notes:
* Definition adapted from WRI et al. (2021).
+ Definition adapted from Penman et al. (2003).

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Disclaimer

The GHG Protocol Global Protocol for Community-Scale Greenhouse Gas Inventories (GPC) is designed to promote best practice GHG accounting and reporting. It has been developed through an inclusive multistakeholder process involving experts from nongovernmental organizations, governments, and others convened by WRI, C40, and ICLEI. While the authors encourage the use of the GPC by all relevant organizations, the preparation and publication of reports or program specifications based fully or partially on this standard is the full responsibility of those producing them. Neither the author organizations nor other individuals who contributed to this standard assume responsibility for any consequences or damages resulting directly or indirectly from its use in the preparation of reports or program specifications or the use of reported data based on the standard.

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About WRI's Contributing Initiatives

While this supplement is a product of an independent project funded by CLUA, the project was conducted in partnership with three relevant initiatives at WRI: Cities4Forests, Land and Carbon Lab, and Global Forest Watch.

Cities4Forests

Cities4Forests is a global network of more than 80 cities committed to conserving, restoring, and sustainably managing trees, forests, and other nature-based solutions for human well-being. Cities4Forests supports cities' efforts on their inner forests (such as urban parks and greenways), nearby forests (such as watersheds), and faraway forests (especially tropical forests) by raising awareness of the benefits of forests, inspiring political action and engagement, providing technical assistance, and facilitating economic analysis, finance, and investment.

Land & Carbon Lab

WRI's Land & Carbon Lab (LCL) is developing a comprehensive monitoring system to track all forms of land cover, land use and land-use change globally, plus the associated carbon stocks and flows. In collaboration with our funder the Bezos Earth Fund, political partnerships like AFR100, and companies like HSBC, we are working to turn complex geospatial data into actionable information that informs strategies, policies, investments, and on-the-ground actions that advance sustainable land management and create resilient landscapes. Ultimately, our information will serve decision-makers that influence land use and land management outcomes at all scales—from corporate leaders and policymakers to Indigenous Peoples and farmers.

GLOBAL FOREST WATCH

Global Forest Watch (GFW) is an online platform that provides data and tools for monitoring forests. By harnessing cutting-edge technology, GFW allows anyone to access near-real-time information about where and how forests are changing around the world. People around the world use GFW every day to monitor and manage forests, stop illegal deforestation and fires, call out unsustainable activities, defend their land and resources, sustainably source commodities, and conduct research at the forefront of conservation.

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GREENHOUSE GAS PROTOCOL

The Greenhouse Gas Protocol provides the foundation for sustainable climate strategies. GHG Protocol standards are the most widely used accounting tools to measure, manage, and report greenhouse gas emissions.