GREENHOUSE GAS PROTOCOL

Land Sector and Removals Guidance
Part 2: Calculation Guidance

Supplement to the GHG Protocol Corporate Standard and Scope 3 Standard

DRAFT FOR PILOT TESTING AND REVIEW (SEPTEMBER 2022)

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This is the Draft for Pilot Testing and Review.
This draft is not yet final and does not represent official Greenhouse Gas Protocol guidance.

This Guidance has been under development through the Advisory Committee and Technical Working Group since early 2020. The draft is now available for pilot testing by the Pilot Testing Group and review by the Review Group. The Review Group is open to any interested stakeholder that wants to participate in the public consultation by reviewing this draft. The pilot testing phase will last 4 months and the review phase will last 2 months.

Following the pilot testing and review phase, the Guidance will be finalized in consultation with the Advisory Committee and Technical Working Group and published in 2023.

If cited, this draft should be referred to as the
"Greenhouse Gas Protocol *Land Sector and Removals Guidance*
(Draft for Pilot Testing and Review, September 2022)".

A full list of contributors, including members of the Advisory Committee, Technical Working Group, Pilot Testing Group, and Review Group, as well as funders, will be provided in the final publication. Members of the Pilot Testing Group and Review Group will be acknowledged based on completion of either pilot testing or review.

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Collecting Data and Quantification

Chapter 16: Collecting Data and Quantification

Calculation Guidance

This chapter provides guidance on collecting data and quantifying emissions and removals (sections 16.1 – 16.4). It also includes methods for allocating emissions and removals (section 16.5) and guidance on assessing uncertainty (section 16.6). This chapter provides general guidance on these topics, while chapters 17-21 provide more detailed data and quantification guidance for specific accounting categories.

This chapter builds directly upon the Greenhouse Gas Protocol Scope 3 Standard, chapter 7 (Collecting Data). This chapter also draws upon the IPCC Guidelines for National Greenhouse Gas Inventories.

To complement this Guidance, the GHG Protocol website provides a database of existing calculation tools and resources to help companies identify more specific calculation resources and gather relevant data.[1]

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16.1 Introduction to quantification methods and data types

A variety of methods and data sources are available to quantify greenhouse gas emissions and removals. Methodological decisions should be made based on a combination of several factors including data and method availability, the company's location within the value chain and level of traceability, and the additional data requirements for removals. Companies should prioritize use of higher accuracy methods and collection of primary data for the GHG sources and sinks that are most significant across their operations and value chain (discussed in section 16.2). Removals require use of higher quality data and methods (discussed further in section 16.2). The sections below provide an overview of quantification methods and data types.

[1] Available at https://ghgprotocol.org/land-sector-and-removals-guidance.

16.1.1 Quantification methods

There are two main quantification types to estimate emissions and removals: direct measurement and calculation.

Direct measurement is the quantification of GHG emissions or removals, or associated carbon stock changes, using direct monitoring of GHG fluxes, mass balance or stoichiometry. Direct measurement of carbon stock changes on the land can be based on repeated measures of carbon stocks within a pre-defined strata using inventory methods.

Measurement-based inventories or sampling approaches involve developing a sampling protocol, selecting representative sampling sites, collecting initial samples, re-sampling according to the sampling protocol, analyzing data for estimated values and uncertainty and reporting the results, sampling and quality control procedures.

Direct remote sensing approaches can directly detect carbon stock changes using remote sensing techniques which may be comparable to direct measurement approaches with proper calibration to ground-based inventory data, though direct remote sensing has not been developed for all sources of carbon stock changes (e.g., soil carbon).

Calculation is the quantification of GHG emissions or removals, or associated carbon stock changes, using empirical, process-based or other models, which can follow the quantification approaches outlined in table 16.1.

Quantification methods can involve a hybrid approach of direct measurements and calculations. For example, direct measurements of carbon stock changes can be combined with calculation approaches to calibrate model-based or remote sensing-based approaches or to develop new emission factors or carbon stock change factors for activity-based approaches.

Table 16.1 Description of quantification types and approaches

Quantification type	Quantification approach	Description of relevant methods	Examples
Direct measurement	Measurement-based approaches	Methods that directly quantify GHG emissions or removals, or associated carbon stock changes, using monitoring of GHG fluxes, mass balance or stoichiometry	Direct on-farm measurement of soil carbon (typically combined with a soil carbon model)
Calculation	Activity-based calculation approaches	Methods that multiply activity data by an emissions factor or carbon stock change factor to determine emissions, removals, or carbon stock changes for a given process	LCA database derived emissions factors; supplier's product level LCAs
	Model-based calculation approaches	Methods that use mathematical modeling techniques to estimate emissions, removals, or carbon stock changes using input variable and fixed parameters calibrated to the specific model applications	Farm-level GHG calculation tools/models
	Remote sensing-based calculation approaches	Data collection methods that use satellite or aerial data to collect data on activities on the land and estimate emissions, removals, or carbon stock changes which are then combined with direct measurements, activity-based approaches or modeling approaches	LiDAR; Satellite deforestation monitoring

Method and data selection depends on a company's location within the value chain. For owned or controlled sources and sinks accounted for in scope 1, producers may have the infrastructure to quantify GHG emissions, removals or carbon stock changes using direct measurement. However, calculations using activity data and emissions factors are also common. For companies calculating scope 3 emissions or removals, calculation-based approaches are more common, though companies should the use the most accurate methods available for activities that are most significant and relevant.

The IPCC *Guidelines for National GHG Inventories* define methodological "tiers" which represents the level of methodological complexity and accuracy. Tier 1 methods are the most simplified methods using global estimates with large uncertainty ranges. Tier 2 methods have intermediate complexity and involve country or management specific data with lower uncertainty ranges. Tier 3 methods require the most intensive data collection and analysis but can lead to more accurate estimates, with reduced uncertainty ranges.

16.1.2 Data types

Data can be classified as primary data or secondary data:

- **Primary data** (e.g., site-specific data) are from specific activities within a company's operations or value chain.
- **Secondary data** are not from specific activities within a company's operations or value chain.

For example, if a company is sourcing dairy products, primary data can include soil carbon measurements from a specific farm where that dairy product is produced. Secondary data, on the other hand, might include data from another dairy farm in the same region used as a proxy, or regional average data from a reputable source.

While input data can be classified as either primary or secondary, the calculation methods described in section 16.1.1 might require a mixture of both data types, resulting in a hybrid calculation. For example, calculating emissions from enteric methane fermentation could involve primary activity data, such as the number of cows on a farm, multiplied by a secondary emissions factor provided by the IPCC or national GHG inventories, representing the average quantity of methane emitted per cow.

16.2 Selecting data and quantification methods

This section provides guidance on selecting data (section 16.2.1) and quantification methods (section 16.2.2).

16.2.1 Guidance on data selection

Data collection efforts are expected to vary based on the sector, the company's location in the value chain, and their level of traceability. Companies should seek to improve traceability by gathering more primary data to support GHG estimates as relevant to meeting their specific business goals.

To ensure efficient use of resources when preparing a GHG inventory, companies should prioritize using primary data and higher quality quantification methods for sources, sinks and activities across scope 1, scope 2, and scope 3 for which emissions, removals, and mitigation opportunities are the greatest. Companies should follow the guidance in the *Scope 3 Standard* (section 7.1) to prioritize data collection efforts.

This Guidance offers flexibility in the data and methods used to estimate GHG emissions, while requiring primary data and greater levels of traceability to account for and report removals as explained in chapter 6 and further described in the section 16.2.2.

Companies should determine data collection methods when selecting the data needed to estimate GHG emissions and removals. Preparing a data management plan can serve as an important first step when selecting data and prioritizing data collection efforts. A data management plan can be used to document the data collection process required to prepare a complete GHG inventory, including the data type, data source, assumptions, collection protocols and data quality information for each relevant activity and source category. For more information, refer to the *Scope 3 Standard*, Annex C (Data Management Plan).

Table 16.2 outlines the advantages and disadvantages of primary and secondary data. Primary data provides a better representation of a company's activities and enables actions taken to improve a company's inventory to be reflected in the data (e.g., farm-level interventions which would not be reflected in secondary data). However, primary data can be more difficult to obtain. Secondary data is more widely available, but it is less representative of a company's activities. Secondary data does not always reflect changes in management that reduce emissions or increase removals because secondary data are not directly linked to the company's activities.

Primary data availability and quality can improve over time with improved traceability. Process-specific or product-specific primary data can better reflect the geographical and temporal boundaries and the relevant practices compared to data from an external source. For example, if a food processing company has access to primary data from the farms that supply the wheat for their products, such data will be more representative of their value chain than secondary data on average practices for wheat growers in the region.

Table 16.2 Advantages and disadvantages of primary and secondary data

	Primary data (e.g., supplier-specific data)	***Secondary data (e.g., industry-average data)***
Advantages	• Provide better representation of the company's specific value chain activities • Enables performance tracking and benchmarking of individual value chain partners by allowing companies to track operational changes from actions taken to reduce emissions at individual facilities/companies and to distinguish between suppliers in the same sector based on GHG performance • Expands GHG awareness, transparency, and management throughout the supply chain to the companies that have direct control over emissions • Allows companies to better track progress toward GHG reduction targets (see chapter 9)	• Allows companies to calculate emissions when primary data is unavailable or of insufficient quality • Can be useful for accounting for emissions from minor activities • Can be more cost-effective and easier to collect • Allows companies to more readily understand the relative magnitude of various scope 3 activities, identify hot spots, and prioritize efforts in primary data collection, supplier engagement, and GHG reduction efforts
Disadvantages	• May be costly • May be difficult to determine or verify the source and quality of data supplied by value chain partners	• Data may not be representative of the company's specific activities • Does not reflect operational changes undertaken by value chain partners to reduce emissions • Could be difficult to quantify GHG reductions from actions taken by specific facilities or value chain partners • May limit the ability to track progress toward GHG reduction targets (see chapter 9)

Source: GHG Protocol *Scope 3 Standard*

Companies should evaluate data quality when prioritizing data collection and selecting data. Data quality is determined by a variety of data quality indications and contributes to how uncertainty is calculated. The main data quality indicators to consider when selecting data include how well the data reflect the relevant timeframe, the technologies used, the geographic region, and the completeness and reliability of the data. Tables 16.3 and 16.4 describe the data quality characteristics that can be applied to evaluate each data quality indicator in a qualitative ranking system from poor to very good. Companies should select the most representative, complete, and reliable data available.

To ensure transparency, companies are required to report a description of the types and sources of data, including activity data, emission factors and GWP values, used to calculate emissions (and removals if applicable), and a description of the data quality of reported data.

Table 16.3 Data quality indicators

Indicator	*Description*
Technological representativeness	The degree to which the data set reflects the actual technology(ies) used
Temporal representativeness	The degree to which the data set reflects the actual time (e.g., year) or age of the activity
Geographical representativeness	The degree to which the data set reflects the actual geographic location of the activity (e.g., country or site)
Completeness	The degree to which the data is statistically representative of the relevant activity. Completeness includes the percentage of locations for which data is available and used out of the total number that relate to a specific activity. Completeness also addresses seasonal and other normal fluctuations in data.
Reliability	The degree to which the sources, data collection methods and verification procedures[2] used to obtain the data are dependable.

Adapted from B.P. Weidema and M.S. Wesnaes, "Data quality management for life cycle inventories – an example of using data quality indicators," Journal of Cleaner Production 4 no. 3-4 (1996): 167-174.

Source: GHG Protocol *Scope 3 Standard* (WRI/WBCSD 2011)

Table 16.4 Example of criteria to evaluate data quality indicators

Score	Representativeness to the activity in terms of:				
	Technology	Time	Geography	Completeness	Reliability
Very good	Data generated using the same technology	Data with less than 3 years of difference	Data from the same area	Data from all relevant sites over an adequate time period to even out normal fluctuations	Verified[3] data based on measurements[4]
Good	Data generated using a similar but different technology	Data with less than 6 years of difference	Data from a similar area	Data from more than 50 percent of sites for an adequate time period to even out normal fluctuations	Verified data partly based on assumptions or non-verified data based on measurements
Fair	Data generated using a different technology	Data with less than 10 years of difference	Data from a different area	Data from less than 50 percent of sites for an adequate time period to even out normal fluctuations or more than 50 percent of sites but for a shorter time period	Non-verified data partly based on assumptions, or a qualified estimate (e.g. by a sector expert)
Poor	Data where technology is unknown	Data with more than 10 years of difference or the age of the data are unknown	Data from an area that is unknown	Data from less than 50 percent of sites for shorter time period or representativeness is unknown	Non-qualified estimate

Adapted from B.P. Weidema and M.S. Wesnaes, "Data quality management for life cycle inventories – an example of using data quality indicators," Journal of Cleaner Production 4 no. 3-4 (1996): 167-174.

Source: GHG Protocol *Scope 3 Standard* (WRI/WBCSD 2011)

Companies should document quality assurance and quality control (QA/QC) procedures in their data management plan. Quality control involves an internal system of routine technical activities to determine and control the quality of the inventory data and the data management processes. Quality assurance involves a third party to check and verify the estimates and assumptions underlying the GHG inventory either through a peer review process or audit to provide an assurance statement as detailed in chapter 15. Such QA/QC procedures should facilitate the improvement of data quality over time. For example, the Global GHG Accounting and Reporting Standard from the Partnership for Carbon Accounting and Financials (PCAF) contains a data quality scoring system which companies can use to develop a data improvement roadmap and track progress over time.[2] QA/QC can also be reported qualitatively, by describing the ways in which a dataset is relevant to a company's activity, and highlighting potential pathways for improvement.

A company's data quality can be verified in several different ways. For example, companies can undergo an audit of their emissions, which also involves hiring a third party, but the auditor would conduct their own data

[2] PCAF, 2020

collection and quantification (see chapter 15 on assurance for additional guidance). Companies can also conduct first-party assurance which means that an individual within the company who is independent of the emissions inventory process conducts internal assurance. A third option is for a company to have their data and calculations peer reviewed, perhaps by other organizations in the same field. Companies should consider adopting a verification method in addition to the required QA/QC reporting requirements.

16.2.2 Guidance on method selection

Given the variety of quantification methods available to estimate land sector GHG emissions and removals, companies should evaluate tradeoffs when selecting methods for various aspects of their GHG inventory (see Table 16.5). When selecting methods companies should consider the following factors:

- Accuracy, continuity, and uncertainty associated with the quantification approach
- Relevance of quantification approach and methods to company's operations and value chain
- Technical expertise required to implement the quantification approach
- Available tools and resources to support quantification.
- Secondary data available for activities relevant to the company
- Primary data requirements for the selected method
- Consistency across datasets which are being directly compared across time

Table 16.5 Advantages and disadvantages of quantification approaches

Quantification Approaches	Advantages	Disadvantages
Activity-based	• Simplest methods to apply	• Often unable to represent specific land management practice changes • Contains the large uncertainty in estimates
Model-based	• Able to represent a range of land management practices, depending on model design and calibration • May cover multiple GHG estimates	• Requires detailed technical expertise to implement • Requires direct measurements to calibrate to site-specific or management-specific conditions
Remote sensing-based	• Able to represent a range of land management practices, depending on model design and calibration • Provides spatially explicit estimates that are more geographically representative • Can improve the accuracy of management activities • Reduce cost of data collection	• Requires detailed technical expertise to implement • Requires direct measurements to calibrate to site-specific or management-specific conditions
Measurement-based	• Able to capture impact of all land management practices,	• Costly and labor intensive • Requires site visits

	depending on sampling design and stratification • Provide the most accurate estimates	• Time consuming

Data requirements also vary by quantification methods and can be an important consideration when selecting methods to quantify land sector GHG emissions and removals. Table 16.6 provides an overview of the data types needed to estimate GHG emissions, removals and/or carbon stock changes by quantification method.

Table 16.6 Examples of data types by quantification method and data type

Quantification approaches	Data type	Example activity data and/or inputs	Example emission factors and/or carbon stock data
Activity-based	Primary data	Product quantity or land area by known sourcing areas	Primary emissions factors or data based on direct measurements from suppliers
	Secondary data	Product quantity by unknown sourcing areas or country of origin	IPCC Tier 1 global default or Tier 2 factors country-specific factors
Model-based	Primary data	Supplier-specific input data from known sourcing areas	Calibration using direct measurements within sourcing region
	Secondary data	Input data based on average practices within the country	Calibration using regional or global average measurements
Remote sensing-based	Primary data	Remote sensing data in known sourcing areas	Direct remote sensing of carbon stocks
	Secondary data	Remote sensing data from known countries of origin	Carbon stocks estimates from Tier 1 or Tier 2 data
Measurement-based	Primary data	Land use and stratification on known sourcing areas	Direct measurements of emissions or carbon stocks in known sourcing areas
	Secondary data	Not applicable (direct measurements are always primary data)	

Emissions vs removals

This guidance offers flexibility in the data and methods used to estimate GHG emissions, while requiring that higher quality methods and primary data be used to calculate removals (see table 16.7). Companies that choose to account for and report CO_2 removals should select quantification approaches where traceability and primary data on the relevant carbon stocks are available to meet the requirements for reporting removals (described further in chapter 6).

Table 16.7 Summary of data and methods requirements for emissions and removals

Accounting Category	Required or optional to report (Chapter 5)	Data	Methods	Uncertainty
Emissions	**Required** (Companies are required to account for and report all emissions)	Companies should use the most accurate, complete, and representative data available	Companies should use the most accurate methods possible (Tier 1, 2, or 3 methods)	Companies should assess and report uncertainty either qualitatively or quantitively (See section 16.6 on uncertainty)
Removals (see chapter 6 for more information)	**Optional** (Companies may account for and report removals if the removal requirements in chapter 6 are met)	**Requires primary data** (Companies are required to use empirical data specific to the sinks and pools where carbon is stored to estimate annual net carbon stock changes)	**Requires methods that incorporate empirical data** (i.e., Tier 2 or 3 methods, but not Tier 1 methods)	**Requires quantitative uncertainty estimates that are statistically significant**, where companies must demonstrate that the selected value for annual net carbon stock changes is conservative and does not overestimate removals given the uncertainty range.

Note: See Chapter 6 for more information on removals accounting.

Scope 3 accounting

Data and methods vary by scope 3 category (table 16.8). Several scope 3 categories require quantifying life cycle impacts. Upstream product-related scope 3 categories—such as category 1 (Purchased goods and services), category 2 (Capital goods), and category 3 (Fuel- and energy-related activities, not included in scope 1 or scope 2)—include all upstream (cradle-to-gate) impacts. Downstream product-related scope 3 categories (categories 9, 10, 11 and 12) include all downstream (gate-to-grave) impacts, disaggregated across the categories.

Table 16.8 List of scope 3 categories

Upstream or downstream	*Scope 3 category*
Upstream scope 3 emissions	**1.** Purchased goods and services **2.** Capital goods **3.** Fuel- and energy-related activities (not included in scope 1 or scope 2) **4.** Upstream transportation and distribution **5.** Waste generated in operations **6.** Business travel **7.** Employee commuting **8.** Upstream leased assets
Downstream scope 3 emissions	**9.** Downstream transportation and distribution **10.** Processing of sold products **11.** Use of sold products **12.** End-of-life treatment of sold products **13.** Downstream leased assets **14.** Franchises **15.** Investments

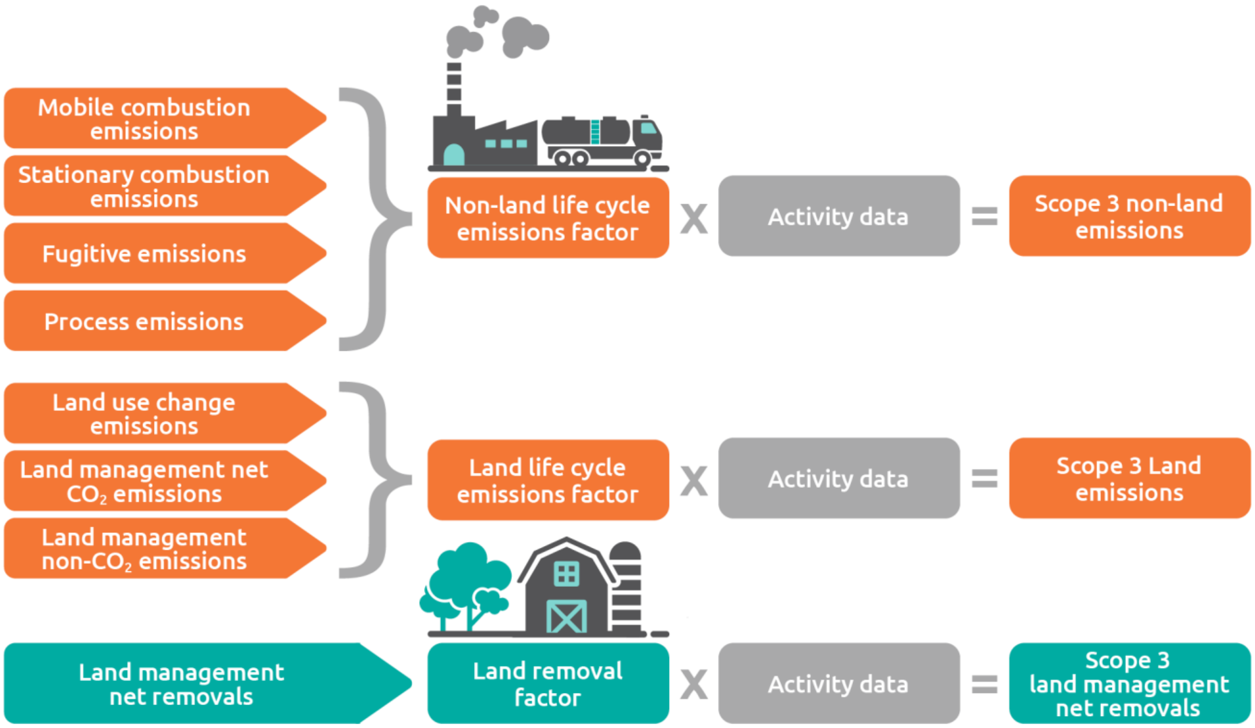
Source: GHG Protocol *Scope 3 Standard*

To account for all emissions (as required in chapter 5), life cycle emission factors for land-based products or materials must include all emissions occurring in the product life cycle and should be disaggregated by accounting category (see figure 16.1), including:

- **Non-land emissions**: includes stationary and mobile combustion emissions, process emissions, and fugitive emissions (reference: *Corporate Standard* and *Scope 3 Standard*)
- **Land emissions**, including,
  - **Land use change emissions:** CO_2 emissions from carbon stock losses due to land use change (reference: chapters 7 and 17)
  - **Land management net CO_2 emissions**: CO_2 emissions from carbon stock changes due to land management (reference: chapters 8 and 18)
  - **Land management non-CO_2 emissions**: GHG emissions from land management excluding biogenic CO_2 emissions (reference: chapters 8 and 19)

To quantify all relevant life cycle impacts, companies may need to use a combination of quantification approaches or hybrid approaches. For example, a company calculating a life cycle emission factor for soy used in their products may use activity-based approaches to estimate GHG emissions from fertilizer application during production, mobile combustion during transportation, and stationary combustion during food processing; remote-sensing based approaches to estimate land use change emissions; and model-based approaches to estimate carbon stock changes from land management. When selecting life cycle emission factors, companies should ensure all relevant source categories are included and document the quantification methods and data associated with the estimates.

Figure 16.1 Source categories for land sector life cycle GHG emissions



Companies are required to separately account for and report emissions and removals (chapter 5). Where carbon stock changes result in net increases or CO_2 removals, such impacts must be quantified separately and not netted within life cycle emission factors to allow for separate reporting of removals from emissions (see figure 16.1). Chapter 6 provides requirements for accounting for removals within a company's operations and value chain.

16.3 Collecting primary data

Primary data can be collected within a company's own operations or provided directly by a company's value chain partners such as suppliers or customers. The ability to collect primary data to support scope 3 accounting depends on the company's value chain traceability and their relationship with value chain partners.

This section provides guidance on prioritizing primary data collection efforts (section 16.3.1), improving traceability (section 16.3.2), spatial resolution of data (16.3.3), use of certification programs (section 16.3.4), sampling design (section 16.3.5) and calibration and validation of modeling and remote sensing-based approaches (section 16.3.6).

16.3.1 Prioritizing primary data collection efforts

Based on section 7.1 of the *Scope 3 Standard*, primary data collection can be prioritized in multiple ways in line with a company's broader business goals.

Prioritizing by emissions

Companies may decide to determine which products are the most emissions-intensive within their inventory and prioritize primary data for those products. For example, an ice cream company might produce equal amounts of ice cream and sorbet, but because dairy is the most emissions-intensive product, they might prioritize gathering primary data for the milk rather than the fruit in sorbet. In this scenario, the majority of the company's emissions would be accounted for using the highest quality data.

Prioritizing by spend

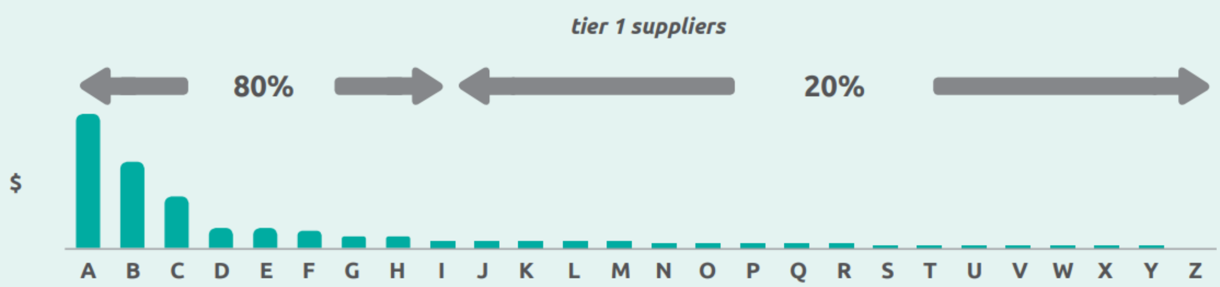
If a company sources many different products and it is difficult to distinguish the relative emissions intensity of one product versus another. Companies might then choose to prioritize data collection for the products that they buy the most of. This decision is built on the assumption that, while the product might not have the highest emissions factor per unit, the emissions attributed to the total quantity of that product purchased would make up a significant percentage of the company's total emissions. For example, a cereal company might purchase a wide range of products such as various grains, milk, and sugar, but wheat is the product that the company purchases the most of. While the emission factor of wheat is likely not larger than other purchased products like milk, the volume of wheat purchased means it is likely that the total portion of the emissions attributed to all wheat is larger than the other supplementary ingredients. Box 16.1 provides an example.

Box 16.1 Example of prioritizing suppliers based on contribution to the company's total spend

As an example, a company may prioritize suppliers by following these steps:

1. Obtain a complete list of the reporting company's total spend or expenditure, by supplier
2. Rank tier 1 suppliers according to their contribution to the reporting company's total spend
3. Select the largest tier 1 suppliers that collectively account for at least 80 percent[8] of spend (see figure 7.4)
4. Within the remaining 20 percent of spend, select any additional suppliers that are individually more than 1 percent of spend or that are relevant to the company for other reasons (e.g., contract manufacturers, suppliers that are expected to have significant GHG emissions, suppliers that produce or emit HFCs, PFCs, or SF_6, suppliers of high emitting materials, suppliers in priority spend categories as defined by the company, etc.)

Figure [7.4] Ranking a company's tier 1 suppliers according to spend



In this example, A-Z represent individual suppliers. The company selects suppliers A through I because they collectively account for 80 percent of the company's spend. The company also selects supplier J because it individually represents more than 1 percent of supplier spend. The company uses secondary data to calculate emissions from activities where supplier-specific data is not collected or is incomplete.

Source: GHG Protocol *Scope 3 Standard* (WRI/WBCSD 2011)

Other criteria

There are many other factors that might go into how a company chooses to improve data quality and collect primary data. As it relates to the land sector, companies might have incentive to improve primary data access if they wish to report removals, which will typically require primary data as they must be spatially explicit. Companies might also choose to prioritize primary data that they either have influence over in order to improve reliability and other quality indicators over time.

In general, collecting primary data and improving data quality over time should be a goal for all companies. As companies improve supply-chain traceability, there will be more opportunities to improve data quality and use more robust calculation methods. However, many barriers can exist beyond simply improving traceability. For example, supplier companies might not be tracking the necessary emissions data. Alternatively, if a supplier is tracking emissions, the data or the methodologies behind it might be proprietary. In cases such, reporting companies may rely on secondary data to fill in the gaps, which is discussed further in section 16.4.

16.3.2 Guidance on improving traceability

Traceability refers to the ability of a company to identify and track activities, and information about those activities, in the value chain of the company, for processes and products both upstream and downstream of their own operations.

Removals reported in a GHG inventory require traceability to the relevant carbon pools to ensure that reported removals meet the principles of permanence, accuracy, and conservativeness. Chapter 6 provides further requirements and guidance for reporting removals.

Additional traceability through primary data is also needed to demonstrate reduced emissions from the implementation of a specific GHG reduction strategies or practices, which would not otherwise be captured through secondary data. For example, if a company sources dairy from a region where some farmers use enteric methane inhibitors, the reporting company would need data at the farm level to use an improved emission factor that is representative of the practice and product being sourced.

Supply chain traceability

Primary data can be distinguished by the position of a given supplier in relation to the reporting company. In addition to the "Tier 1, 2, 3" system employed by the IPCC to classify quantification methods, the "tier" terminology is also used to describe the position of suppliers relative to the reporting company within a supply chain. Primary data from a tier 1 supplier refers to primary data that comes from the company directly supplying the reporting company. Primary data from a tier 2 supplier refers to primary data that comes from a company that supplies the reporting company's tier 1 suppliers. The numbering of tier X suppliers continues to increase to the producer of the biogenic materials and the associated land management units. For example, a company that sells furniture might have primary data from the furniture manufacturer (their direct or tier 1 supplier), primary data from the sawmill (the furniture company's tier 2 supplier) that produces the wood products sold to the furniture manufacturer, and primary data from the forest management company (the origin supplier) that grows the trees and harvests timber sold to the sawmill.

Improving traceability by identifying increasing tiers of suppliers back to the original land management unit associated with production of the raw materials can provide reliable primary data. Doing so can enable a company to use higher-tier calculations or to apply direct measurements to improve estimates. In some cases, the supplier is known but cannot provide primary data on emissions, removals or carbon stock changes. However, the company may still be able to provide relevant information regarding production practices, site conditions, site history, and other information, allowing for higher-tier methods using primary activity data combined with secondary emission factors or carbon stock data.

If the supplier is unknown, the company should work to increase the availability of primary data by identifying their suppliers and in the meantime may either use global, national or regional secondary data to quantify GHG emissions. Once companies achieve better value chain traceability, companies can work to improve suppliers' ability to provide primary data and improve the quality of such data.

16.3.3 Spatial resolution

Quantification methods depend on data availability across spatial levels for each source category. The spatial resolution of primary data can be classified based on the following scales:

1. **Harvested area scale**: A spatially explicit area of agricultural or forest land that was harvested at a given time to produce the relevant raw materials.
2. **Land management unit scale**: A predefined, spatially explicit area of a given land use, managed according to a clear set of objectives in accordance with a single land management plan.
3. **Sourcing region scale**: A predefined, spatially explicit land area that supplies harvested biogenic material to the first collection point of processing facility in a value chain. A sourcing region is comprised of land management units and may also be referred to as a supply shed or supply base. This scale could include lands across multiple states, provinces or countries.
4. **Jurisdictional scale**: A spatially explicit land area, often defined relative to political boundaries, that contains lands where harvested biogenic materials were produced. Jurisdictions can include subnational jurisdictions (e.g., municipality, country, state, province, etc.).
5. **Global scale**: A spatially explicit land area representative of all lands associated with production of harvested biogenic materials.

Selecting a spatial scale has implications across various metrics and land uses for companies to consider. While data is often more readily available at broader, more generic spatial scales, that choice limits the relevance of the data to the corporate activity in question. For example, using a global or jurisdictional scale to account for the emissions associated with livestock production or crop harvest would not adequately capture the benefits of specific actions or interventions to incentivize practices that reduce emissions or enhance removals at the land management unit scale.

Conversely, using narrower spatial scales such as a harvested area or land management unit scale would be far more accurate in accounting for the practices of a given supplier, but companies sourcing land-based products are far less likely to have access to such specific data sources.

The implications of spatial scale selection for certain land-based products, such as forest products and associated forest carbon stock changes, are complex. For further guidance, see section 8.2.3 in chapter 8.

In order to balance the need for a consistent approach to emissions and removals accounting over time with the flexibility needed to account for all supply chain activities, companies are required to use a consistent spatial boundary. Selecting that boundary is left up to the company after considering the strengths and weaknesses of each option described in this section.

Table 16.9 highlights which spatial boundaries can be used for land use change and land management accounting based on the level of traceability and provides examples of potential data sources.

Table 16.10 provides examples of data and quantification methods that may be applied based on the spatial resolution and the company's level of traceability. For each method listed below, several resources can be found in the supplementary database of existing tools.[3]

[3] Available at https://ghgprotocol.org/land-sector-and-removals-guidance.

Table 16.9 Illustration of spatial traceability required to report removals, and the types of data required

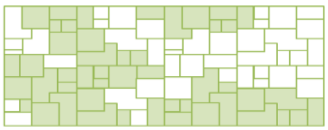
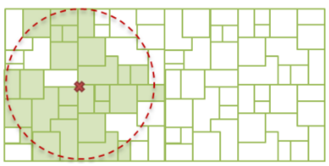
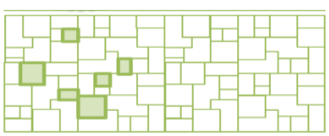
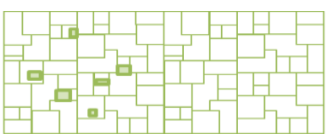
	Spatial boundary	Level of traceability	Data specificity
	Global	No knowledge of region of origin	Global average secondary data
	**Jurisdictional**	Known subnational jurisdiction, country, or political region (e.g., EU) of origin	Average national or regional secondary data for attributable managed land in the jurisdiction
	**Sourcing region**	Known first collection point or processing facility	Primary data on attributable managed lands in the sourcing region(s) or secondary data representative of average management for lands within the sourcing region(s)
	**Land management unit**	Known land management units of origin (e.g., forest management unit, farm)	Primary data from producers for the specific land management unit(s)
	**Harvested area**	Known field or forest stand of origin	Primary data from producers for the specific harvested area(s)

Table 16.10 Examples of data and methods depending on spatial resolution and traceability

	Accounting categories:	**Land use change emissions**	**Land management non-CO_2 emissions**	**Land management net CO_2 emissions (biogenic)**	**Land management net CO_2 removals (biogenic)**
	Guidance or requirement:	Companies are required to account for and report emissions (chapter 5). Companies should use the most geographically representative data (see chapters 7 and 8 for more specific guidance).			Companies may account for and report removals if removals requirement are met
Level of physical traceability to where products are sourced from	**Unknown origin**	Global sLUC	Global average emission factors	Global average carbon stock change factors	Does not meet primary data or traceability requirements
	Jurisdiction of origin	Jurisdictional level sLUC	National or regional average emission factors	National or regional average carbon stock change factors for attributable managed lands	Does not meet primary data or traceability requirements
	Sourcing region of origin	Sourcing region sLUC	Primary data specific to sourcing region or national average emission factors	Sourcing region carbon stock change data within attributable managed lands	*Subject to open question #3 (chapter 8, box 8.3)*
	Land management unit of origin	dLUC	Primary data specific to the LMU or national average emission factors	Primary carbon stock change data specific to the LMU	Primary carbon stock change data specific to the LMU
	Harvested area of origin	dLUC	Primary data specific to the stand or field, or national average emission factors	Primary carbon stock change data specific to the stand or field	Primary carbon stock change data specific to the stand or field

16.3.4 Certification programs

Certification programs are one tool a company can use to help improve their traceability systems. The applicability of certification programs for GHG accounting depends on the chain of custody model used by the certification program. A chain of custody chain model is the approach taken to transfer the information associated with a material or product as ownership transfers from one entity to another in a supply chain, from the land management unit(s) (LMU) where the material was produced to the product's end use.

Five general chain of custody models used by certification programs are: identity preserved, segregation, controlled blending, mass balance, and book and claim. Table 16.11 describes each model and explains the relevance to GHG accounting under this Guidance.

For scope 3 accounting, companies that source land-based products (e.g., crops, forest products or animal products) need physical traceability of their purchased goods to properly account for upstream scope 3 emissions or removals on the lands associated with that material. Scope 3 emissions and removals accounting is based on the allocation of GHG emissions and removals from all product life cycle phases to the products purchased or sold by a given company. Accounting for GHG emission and removals from the production of land-based products requires physical traceability of the materials or products to their origin, either to a specific LMU or broader sourcing region, based on transfers through the supply chain.

Companies may use chain of custody models to demonstrate physical traceability of the products a company purchases to a specific LMU or multiple LMUs. Certification programs can also help improve data reliability and verification (discussed in section 16.2) if the certification includes data audits. A certification program may have access to data regarding the category of land conversion, spatial boundary of land management units or sourcing region, and/or emissions factors that can be used to support a company's scope 3 GHG emissions accounting.

Companies that use such programs are required to report the type of certification programs or chain-of-custody models used (chapter 7).

Table 16.11 Chain of custody models used by certification programs and relevance to GHG accounting

Chain of Custody Model	Description (Source: ISO 22095:2020)	Establishes physical traceability to land management unit(s)?	Relevance for land use change (LUC) emissions accounting	Relevance for land management carbon stock change accounting
Identity Preserved	Chain of custody model in which the materials or products originate from a single source and their specified characteristics are maintained throughout the supply chain.	Yes, to unique land management units (LMUs) for identity preserved materials	Supports dLUC accounting based on LMUs associated with identity preserved materials.*	Yes, allows for carbon stock change accounting in LMUs associated with identity preserved materials
Segregation	Chain of custody model in which specified	Yes, to multiple LMUs for	Supports dLUC accounting based on LMUs	Allows for carbon stock change accounting in LMUs associated with

	characteristics of a material or product are maintained from the initial input to the final output.	segregated materials	associated with segregated materials.*	segregated materials (*subject to open question #3 in chapter 8, box 8.3, on LMU vs sourcing region traceability*)
Controlled Blending	Chain of custody model in which materials or products with a set of specified characteristics are mixed according to certain criteria with materials or products without that set of characteristics resulting in a known proportion of the specified characteristics in the final output.	Yes, to multiple LMUs for the known share of materials	Supports dLUC accounting based on the LMUs associated with the known share of products.* The other share of products must use sLUC accounting based on the known sourcing region or jurisdiction.	Allows for carbon stock change accounting in LMUs associated with the known share of products (*subject to open question #3 in chapter 8, box 8.3, on LMU vs sourcing region traceability*)
Mass Balance	Chain of custody model in which materials or products with a set of specified characteristics are mixed according to defined criteria with materials or products without that set of characteristics.	No, does not ensure physical traceability to specific land management units	Cannot support dLUC accounting; companies should use sLUC accounting based on the known sourcing region or jurisdiction.	No, does not ensure physical traceability
Book and Claim	Chain of custody model in which the administrative record flow is not necessarily connected to the physical flow of material or product throughout the supply chain.	No, credits do not ensure physical traceability to specific land management units	Cannot support dLUC accounting; companies should use sLUC accounting based on the known sourcing region or jurisdiction.	No, does not ensure physical traceability

Note: *Identity preserved, controlled blending, and segregated models making zero-deforestation claims can only be used to claim zero emissions for dLUC if the certification provides information stating that no deforestation or conversion occurred within the 20 year or greater LUC assessment period.

Each chain of custody model described in table 16.11 involves defining the extent to which the products in a supply chain can be traced to their origins. However, the physical traceability of supply chain outputs necessary for scope 3 accounting is not guaranteed by all chain of custody models.

The identity preserved, segregated, and controlled blending models provide the highest integrity methods for traceability to certified suppliers by either physically separating materials or tracking the mixing process to ensure a known quantity of purchased materials can be directly related to certified sources. As described in the ISEAL Chain of Custody guidance[4], only these three models guarantee physical traceability.

Mass balance and book and claim models, on the other hand, do not guarantee a physical link between the output product and the sustainability claim made by the certification. A product certified through mass balance may contain material that does not originate from the certified source. Mass balance is a common approach used by certification bodies that can support the level of traceability needed for environmental accounting, provided the mass balance system has appropriate accountability mechanisms. Certification programs should ensure the certification system protects against double counting by 1) ensuring that quantities of "improved production volumes" under mass balance do not exceed the actual production from those improved locations, and 2) that exclusivity of the benefits is guaranteed to the purchaser of that good. As book and claim systems are not necessarily specific to the reporting company's supply chain, companies can separately report certification claims but cannot use such information from certification programs with book and claim models to support scope 3 GHG accounting.

16.3.5 Sampling design for primary data collection

The first step in measurement-based approaches is to determine where to collect samples. In the case of measuring soil carbon stocks, methods like k-means clustering combined with point randomization or conditional Latin Hyper Cube sampling can be used to generate a set of sampling points based on factors that are known to affect soil carbon, like soil mineralogy, soil texture, vegetation, and climate. For scope 1 accounting companies should generate a sampling approach based on all their land assets. For scope 3 accounting, sampling points can be used to parameterize and verify model-based estimates. In this later case, a set of lands should be sampled that represent the major soil, climate, and production system types within a company's supply chain. Because of the cost associated with soil measurement, companies should collaborate across the supply chain to coordinate measurement where scope 3 portfolios overlap between companies. Soil carbon baseline and soil carbon change measurements should be conducted on the same lands and using the same sampling protocols.

16.3.6 Calibration and validation of modeling and remote sensing-based approaches

Model-based and remote sensing-based quantification approaches require some calibration to ensure carbon stock change estimates and associated uncertainty estimates are relevant to the climate, ecology, land use and land management practices within the region under analysis. Calibration is the process of refining a model's structure or parameters to improve estimates for a given application based on measured values specific to that application in order to use these methods to report removals. In the context of GHG inventory accounting, companies should calibrate model-based and remote sensing-based quantification methods using primary data specific to the land area, management practices and GHG impacts (i.e., carbon stock changes or GHG emissions) under analysis. Companies should include a description of the process undertaken to calibrate the model, including reference to the primary data used to calibrate the model and its applicability to the GHG impacts being estimated.

To evaluate the performance of calibrated models companies using model-based or remote sensing-based quantification methods should validate their model estimates against measured values. Any model validation

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[4] Available at: https://www.isealalliance.org/sites/default/files/resource/2017-11/ISEAL_Chain_of_Custody_Models_Guidance_September_2016.pdf.

must use a separate dataset, independent of the calibration data, to validate the model and evaluate model performance. Companies should include a description of the uncertainty in model estimates after model calibration as evaluated during model validation.

16.4 Evaluating secondary data and filling data gaps

Where primary data is not available, secondary data can be used. This section provides guidance on using secondary data or proxy data to fill data gaps.

16.4.1 Selecting secondary data

Companies should follow the data quality criteria in table 16.3 when selecting secondary data. Companies should assess the regional, temporal, or technological relevance of the data and ensure that any secondary data used are technologically, temporally, and geographically representative. Data should also be based on peer-reviewed scientific literature, government statistics, reports published by international institutions confirming the estimated value and associated uncertainty over multiple studies. Where uncertainty between data sources exists, conservative assumptions and values should be used.

A non-exhaustive list of databases, models, and tools that companies may use as secondary data can be found on the GHG Protocol website.[5]

16.4.2 Proxy data

When available secondary data do not meet a company's quality criteria, they may use proxy data to fill any remaining gaps. For example, if there are no good data available for dairy produced in Germany, but there are high-quality, peer-reviewed data for dairy produced in Denmark, a company sourcing dairy from Germany might opt to use the better data from a different but similar geographic region.

16.5 Allocation of emissions and removals across multiple products

Allocation is the process of partitioning GHG emissions or removals from a single system among its various outputs. Allocation is necessary when a single system produces multiple outputs and GHG data is only quantified for the entire system as a whole. In such a case, emissions or removals from the shared system need to be allocated to (or divided between) the various outputs. Allocation is not necessary if a system produces only one output or emissions/removals from producing each output are separately quantified.

When companies use primary data from suppliers or other value chain partners to calculate scope 3 emissions or removals, companies may need to allocate emissions. Likewise, companies may need to use allocation when providing primary data to customers that are accounting for their scope 3 emissions or removals.

Allocation of primary data is necessary when a company sources goods from a supplier that produces multiple outputs (e.g., a lumber company that purchases roundwood from a forest management company that also sells logging residues or other species of wood), but GHG data is only available at a level more aggregated than the process that produces the product the reporting company purchases.

This can occur in two situations: 1) the supplier produces its various products in distinct independent manufacturing/production processes but does not have product-specific information, and 2) the suppliers'

[5] Available at https://ghgprotocol.org/land-sector-and-removals-guidance.

products are manufactured in joint manufacturing/processing facilities. The need for allocation introduces uncertainty that differs in these two situations.

In the case of independent manufacturing processes, potential error can occur if the allocation process attributes a proportionate amount of emissions to a reporting company based on the proportion of goods purchased relative to what the supplier produces. If the reporting company sources products with emissions intensities lower than the supplying company's average, the reporting company's emissions would be overestimated. The inverse is true as well.

In the case of joint production processes, allocation consists of "artificially" attributing the emissions from that production processes to the multiple products manufactured at the same time. This type of allocation can be done in multiple ways, such as based on a factor such as weight or price.

Because allocation methods can lead to over- or under-estimation of actual emissions and removals between companies, the multiple companies involved in allocating emissions and removals from a single process should use consistent allocation methods between them. Companies can ensure consistent allocation through contractual agreements or other mechanisms. Where supply chain traceability is limited, this will be a challenge, but companies should work towards consistent allocation over time. In line with the conservativeness principle, to avoid under-reporting of emissions or over-reporting of removals, companies should establish agreements between the various entities reporting direct and indirect emissions and removals that specify which company(ies) account for what proportion of emissions and removals. For example, if a given process results in 100 t CO_2 removals, the multiple companies involved should not collectively report more than 100 t CO_2 removals.

Allocation is less relevant to secondary data, since an allocation approach has already been chosen when using secondary data for purchased goods and services and emission factors provided for single products. Still, the allocation principles described below can be useful in selecting the most appropriate secondary data.

Refer to chapter 17 for allocation guidance for land use change.

16.5.1 Allocation methods for co-products

Companies should follow the decision tree in figure 16.2 to select an allocation approach. Whenever possible, allocation should be avoided. This can be achieved by collecting more detailed data, such as product-level GHG data (see *Scope 3 Standard*, chapter 8 for more details).

If avoiding allocation is not possible, companies should select the allocation approach that:

- best reflects the causal relationship between the production of the outputs and the resulting emissions;
- results in the most accurate and credible emissions estimates;
- best supports effective decision-making and GHG reduction activities; and
- otherwise adheres to the principles of relevance, accuracy, completeness, consistency and transparency.

Different allocation methods can yield significantly different results. Companies that have a choice between multiple methods for a given activity should evaluate each method to determine the range of possible results before selecting a single method (e.g., conduct a sensitivity analysis).

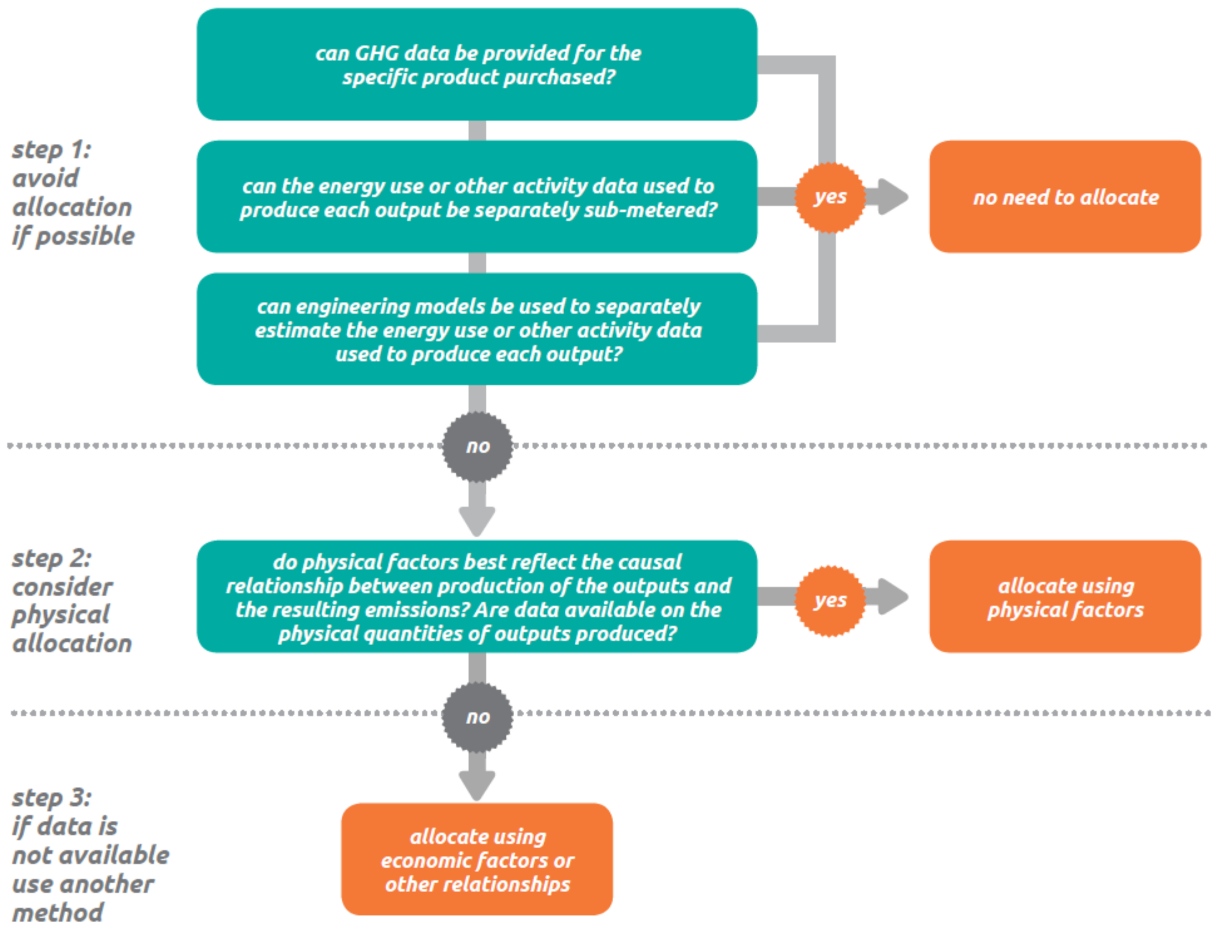
Following the decision tree, companies should consider physical allocation (if physical factors best reflect the casual relationship between production of the outputs and the resulting emissions or removals). If physical data is not available, companies should consider allocation using economic factors or other relationships.

To allocate impacts for the land sector, several different allocation methods can be applied to identify emissions of a single product. Allocation methods can be based on physical allocation based on an underlying physical relationship between inputs/outputs and the emissions or removals generated or economic allocation based on the market value of the inputs/outputs. Allocation methods can be applied to metrics such as net changes in carbon stocks, emissions, removals, etc.

Physical allocation involves calculating the proportion of emissions attributed to a product based on a physical attribute such as mass, volume, or energy. For example, using mass allocation, if a company purchases 50% of the goods produced from a supplier by mass, the purchasing company would allocate 50% of the supplier's emissions in their upstream scope 3 emissions. This method is only accurate so long as the chosen physical attribute is a proxy for emissions intensity, meaning that the heavier or larger items are responsible for more emissions.

On the other hand, economic allocation attributes emissions based on the price of a commodity relative to the price of all products from a given supplier. For example, if a company purchases 50% of the total market value of all products from a supplier, the purchasing company would be allocated 50% of the supplier's emissions. Like physical allocation, this method assumes price is a proxy for emissions intensity. If the less expensive products are less emissions-intensive, the allocation would become skewed.

Figure 16.2 Decision tree for selecting an allocation approach



Source: GHG Protocol *Scope 3 Standard*

16.5.2 Allocation for waste

Waste is an output of a system that has no market value. If a system or process produces waste during production, no emissions or removals from the system or process should be allocated to the waste. All emissions and removals from the system should instead be allocated among the system's other outputs. For example, if company A acquires biogenic waste from company B without paying for it, zero emissions and zero removals from company B's production process are allocated to the waste.

If waste becomes useful and marketable for use in another system, it is no longer considered waste and should be treated like other types of outputs. Economic allocation is expected to yield more representative estimates when:

- a co-product was previously a waste output that acquires value in the marketplace as a replacement for another product, or
- a co-product would not be produced by the common system without the market demand for the primary product and/or other valuable co-products (e.g., by-catch from lobster harvesting).

The preceding guidance does not apply to scope 3, category 5 (Waste generated in operations) or scope 3, category 12 (End-of-life treatment of sold products). Companies should account for all emissions related to waste within scope 3, category 5 and category 12.

Companies may use the recycled content allocation method (outlined in section 16.5.3) for post-consumer waste that is recycled (e.g., used cooking oil, recovered fiber) or reused (e.g., material/residue that is reused as a material input into another process) regardless of the market value of the waste. Companies following this approach are required to report evidence that the waste is post-consumer and that the waste has been reused or recycled.

16.5.3 Allocation for recycling

Recycling occurs when a product or material exits the life cycle of one product to be reused or recycled as a material input into another product's life cycle.

Companies may both purchase materials with recycled content (e.g., recovered paper) and sell products that are recyclable (e.g., paper). The *Scope 3 Standard* describes system boundaries for recycling, based on the recycled content allocation method. Using this approach, the life cycle of acquired recycled material is assumed to start with the recycling process. Therefore the use of recycled material is not associated with any impacts upstream of the recycling process, such as land use change, land management emissions, land management removals, land tracking metrics, or other processes upstream of recycling (e.g., upstream fossil fuels emissions associated with harvesting the fiber). All subsequent emissions in the life cycle (beginning with the recycling process) are accounted for.

Under the recycled content method, companies account for upstream scope 3 emissions from recycling processes in category 1 and category 2 when the company purchases goods or materials with recycled content. In category 5 and category 12, companies should account for emissions from recovering materials at the end of their life for recycling but should not account for emissions from recycling processes themselves (these are instead included in category 1 and category 2 by purchasers of recycled materials).

Companies should not report negative or avoided emissions associated with recycling in scope 1, scope 2, or scope 3. Any claims of avoided emissions associated with recycling should not be included in, or deducted from, the scope 3 inventory, but may instead be reported separately from scope 1, scope 2, and scope 3 emissions. Companies that report avoided emissions should also provide data to support the claim that emissions are avoided (e.g., that recycled materials are collected, recycled, and used) and report the methodology, data sources, system boundary, time period, and other assumptions used to calculate avoided emissions. For more information on avoided emissions, see section 9.5 of the *Scope 3 Standard*.

16.6 Managing data quality and uncertainty

Uncertainty comes with the use of any data or model and can be analyzed qualitatively and/or quantitatively. Identifying and documenting sources of uncertainty can assist companies in understanding the steps required to help improve the inventory quality and increase the level of confidence users have in the inventory results.

Companies are required to assess the uncertainty of any removals reported in the GHG inventory (see chapter 6). Companies should assess the uncertainty associated with methods and data used to calculate emissions. Companies should report the results, either qualitatively or quantitatively, including information on the causes and magnitude of uncertainties in emission estimates and an outline of policies in place to improve inventory quality.

16.6.1 Types of uncertainty

The main categories of uncertainty are parameter uncertainty, scenario uncertainty, and model uncertainty. Parameter uncertainty can stem from measurement error or inaccurate approximation. Measurement error is most relevant for direct emissions data, emissions factors, and activity data. It stems from incomplete knowledge of the parameter and how well it fits the required use. For example, a national emissions factor that is applied to a particular farm might be an over- or underestimation. It can also occur due to error in direct physical measurements in-situ, such as error associated with a measurement device. This type of error can be statistically quantified using a probability distribution with standard deviations and can be qualitatively addressed by improving data quality.

Scenario uncertainty occurs when there are many different options for doing a certain calculation, each of which would yield different results. Companies can assess this type of uncertainty with a sensitivity analysis, which calculates the range of values possible under the various scenarios. Selecting the most relevant and best-quality data can minimize this type of uncertainty. Narrowing down the potential scenarios to ones that are most likely to occur will lead to more accurate calculations.

Lastly, model uncertainty stems from the use of models with built-in assumptions that are not widely relevant. Models are simplified representations of physical processes and may leave out certain components to focus on one specific process. While this may be useful to learn about the process in question, including the foregone components may lead to different results, and thus introduces modeling error. For example, a forest management company might model forest growth using a constant growth rate as an approximation for carbon stocks, when forest growth is really an S-curve. While the linear growth rate is probably a good approximation for the accumulation of carbon in the forest, it introduces some measurable error. This type of error can be addressed by improving the extent to which a model reflects the processes in question.

16.6.2 Guidance on estimating uncertainty

Qualitative approaches include an analysis of shortcomings of data collection methodology or potential model errors that may have occurred. For example, a qualitative uncertainty assessment might include comments on the geographical or temporal relevance of the data or might discuss some of the ways in which a model might over-simplify the physical processes being analyzed. For more information on estimating qualitative uncertainty, see the GHG Protocol *Policy and Action Standard* (chapter 12, section 12.6).[6]

[6] Available at https://ghgprotocol.org/policy-and-action-standard

It is also possible to quantify the uncertainty and error of calculations in several ways. For example, error propagation quantifies the combined impact of the uncertainty of all parameters in a calculation. Error propagation begins with assessing single parameter uncertainty, which can be done in many ways including:

- Default uncertainty values from the literature or commercial database
- Survey of experts to estimate an upper and lower bound
- Probability distributions and standard deviation

Alternatively, Monte Carlo simulations are a method of error propagation that determine the probability of parameter values using random sampling. Each single parameter uncertainty must be calculated as a probabilistic distribution, and the simulation takes many randomized combinations of potential values of individual variables in order to come up with an uncertainty range for the assessment as a whole.

For further information on uncertainty, see the *Scope 3 Standard* (Appendix B)[7] and the *Policy and Action Standard* (chapter 12).[8]

[7] Available at https://ghgprotocol.org/standards/scope-3-standard

[8] Available at https://ghgprotocol.org/policy-and-action-standard

17

Land Use Change and Land Tracking Calculation Guidance

Chapter 17: Land Use Change and Land Tracking

Calculation Guidance

This chapter provides calculation guidance to fulfill the land use change accounting requirements explained in chapter 7. Chapter 7 includes both land use change metrics (direct land use change emissions and statistical land use change emissions) as well as land tracking metrics (indirect land use change emissions, carbon opportunity costs, and land occupation). Companies are required to account for direct land use change (dLUC) emissions or statistical land use change (sLUC) emissions, as well as at least one land tracking metric.

Sections in this chapter

17.1 Introduction to land use change and land tracking metrics

Land use change (LUC) accounting helps companies measure carbon stock losses occurring in the transition from one land use category to another (e.g., forest to cropland), as well as from one land use subcategory to another (e.g., natural to planted forest). This chapter provides guidance on the data, methods, and equations required to calculate emissions and other metrics related to land use change. See table 17.1 for an overview of the metrics related to land use change.

Table 17.1 Metrics related to land use change

Metric	Definition	Unit of Measure	Scope(s) and relevant section
Direct land use change (dLUC) emissions	Emissions (primarily from carbon stock losses) due to recent (previous 20 years or more) land conversion directly on the area of land that a company owns/controls or on specific lands in the company's value chain	CO_2e	Scope 1, scope 2, and scope 3 emissions; see section 17.2
Statistical land use change (sLUC) emissions	Emissions (primarily from carbon stock losses) due to recent (previous 20 years or more) land conversion within a landscape or jurisdiction. sLUC can serve as a proxy for dLUC where	CO_2e	

	specific sourcing lands are unknown or when there is no information on the previous states of the sourcing lands		
Indirect land use change (iLUC) emissions	Emissions (primarily from carbon stock losses) due to land conversion on lands not owned or controlled by the company, or in its value chain, induced by change in demand for (or supply of) products produced or sourced by the company	CO_2e	Scope 1, scope 2, and scope 3 land tracking; see section 17.3
Carbon opportunity costs (COC)	Emissions from total historical carbon losses from plants and soils on lands productively used (this quantity also represents the amount of carbon that could be stored if land in production were allowed to return to native vegetation)	CO_2e	
Land Occupation	The amount of land occupied for a certain time to produce a product	hectares	

17.2 Calculation approaches for direct land use change emissions and/or statistical land use change emissions

This section describes the various approaches to calculate *Land use change emissions* using dLUC and/or sLUC metrics.

Companies that own or control land should apply equation 17.1 to estimate scope 1 *Land use change emissions* using dLUC metrics.

Equation 17.1 Land use change emissions from known areas

$$GHG_{LUC,y} = GHG_{dLUC,y} \times TDF_y$$

Description		Unit	Source
$GHG_{LUC,y}$	GHG emissions from land use change in year *y*, by GHG	(tonnes GHG)	Calculated
$GHG_{dLUC,y}$	GHG emissions from direct land use change on lands owned or controlled by the reporting company in year *y* of the assessment period, by GHG (see section 17.2.2)	(tonnes GHG)	Calculated (eq. 17.2)
TDF_y	Time discounting factor for year *y* of the assessment period (see section 17.2.3)	(dimensionless)	Default value (table 17.4)
y	Year in the assessment period		Subcategory

Calculation of scope 3 dLUC or sLUC can range from the global level (IPCC Tier 1) to the farm or plot level (Tier 3), generating different values. More effective modeling and spatial precision increases the certainty and accuracy of direct land use change emissions estimates. The calculation approach depends upon the level of traceability available to the company regarding the source of a given product and what land(s) it comes from, as described in table 17.2.

1 **Table 17.2 Calculation of dLUC or sLUC depending on level of traceability**

Level of traceability	LUC calculation approach	Description
High: Known land management unit(s) or harvested area(s)	Estimate dLUC emissions in known land management unit(s) or harvested area(s) (equation 17.3)	The company has knowledge about the land management unit (e.g., farm, plantation or ranch) or harvested area (e.g., field or forest stand) where the land-based product was produced. In such cases, the assessment of recent LUC emissions relies on calculating dLUC metrics based on carbon stock losses and GHG emissions from land use change within the spatially explicit boundaries (e.g., polygon data of known farms) during the assessment period for the land management unit or harvested area. dLUC at this level of traceability may be calculated using spatially explicit data collected through remote sensing or management data on historic land use change for the given area and physical measurement, remote sensing or peer-reviewed publications on carbon stocks pre- and-post conversion within the given area.
Medium: Known sourcing region(s)	Estimate sLUC emissions in known sourcing region(s) (equation 17.4)	The company has knowledge about the sourcing region of the land-based product (for example, it can trace its purchased products or materials back to the first collection point or processing facility). In such cases, the assessment of recent LUC emissions relies on calculating sLUC metrics, which allocates the total LUC emissions in the known sourcing region based on the relative occupied land area for products (shared responsibility approach) or relative crop or other product expansion (product expansion approach). Statistical land use change is a combination of both direct and indirect land use change emissions that cannot be clearly separated or disaggregated due to the lack of traceability to specific lands where the products were produced. The allocation approach considers statistical data on products produced in the sourcing region (area occupied by all land-based products, or expansion/contraction of other land use categories) to attribute LUC to the product(s) in the value chain of the reporting company. Data required to calculate sLUC based on the shared responsibility method include the total harvested area across all products within the sourcing region. The product expansion approach uses data on the relative expansion of a specific product within the relevant spatial boundary. National-level data can be found in databases such as FAOSTAT. Alternatively, tools are available for calculating sLUC.

		The GHG Protocol website provides a non-exhaustive list of such resources.[9]
Limited or no traceability: Known country or region of origin, or unknown origin	Apply a published sLUC emission factor, or Estimate sLUC emissions in known jurisdiction(s) (equation 17.4)	The company only has knowledge of the region, country or subnational jurisdiction where it is sourcing the land-based product, or it does not know the origin of the product at all. In these cases, the most straightforward approach is to calculate sLUC using emission factors from a database, or using a tool, as described on the line above. Database provides and tool developer can publish sLUC emission factors following the calculation guidance provided in this chapter. Companies should apply country-specific sLUC emission factors by country, product and year where the country of origin of the product is known. Companies should apply global sLUC emission factors by product and year where the origin of the products are unknown.

Statistical land use change is a way to approximate the risk of direct land use change and may be used as a proxy for dLUC. However, sLUC lacks spatial precision and relies on collective action to improve performance in this metric over time. This is because sLUC allocates total LUC estimates across the broader landscape or entire jurisdictions, which includes the actions of many actors in the assessed area, rather than just one company.

Companies that source land-based products or have other land related impacts in their value chain should apply equation 17.2 to estimate scope 2 or scope 3 *Land use change emissions* based on their traceability for different product types. Companies may use dLUC or sLUC metrics to determine a LUC emission factor as follows:

- Where companies have physical traceability to the land management unit(s) or harvested area(s) of origin for products in their value chain they may apply equation 17.3 to estimate a dLUC emission factor for each unit, by product type, by year.
- Where companies have physical traceability to the sourcing region(s) or jurisdiction of origin for products in their value chain they may apply equation 17.4 to estimate a dLUC emission factor for each sourcing region or jurisdiction, by product type, by year.
- Where companies only know the country of origin for products in their value chain they may apply published sLUC emission factors by country, by product type, by year that follow the methods outlined in equation 17.4.
- Where the origin of their products is unknown, companies may apply published global sLUC emission factors by product type, by year that follow the methods outline in equation 17.4.

[9] Available at https://ghgprotocol.org/land-sector-and-removals-guidance

Equation 17.2 Land use change emissions from products purchased and LUC emission factors

$$\mathbf{GHG}_{\mathbf{LUC},y} = \sum_{a}\sum_{p}\left(\mathbf{A}_{a,p,y} \times \mathbf{EF}_{\mathbf{LUC},a,p,y}\right)$$

Description		Unit	Source
$GHG_{LUC,y}$	GHG emissions from land use change in year *y*, by GHG	(tonnes GHG)	Calculated
$A_{a,p,y}$	Amount of product purchased in area *a*, by product type *p*, in year *y*	(tonnes or m^3 product)	User input
$EF_{LUC,a,p,y}$	LUC emission factor for area *a*, by product type *p*, in year *y*	(tonnes GHG per product)	Calculated (eq. 17.3, 17.4)
a	Area of assessment		Subcategory
p	Product or material type		Subcategory
y	Year in the assessment period		Subcategory

Equation 17.3 Land use change emission factors based on dLUC metrics

$$\mathbf{EF}_{\mathbf{dLUC},a,p,y} = \mathbf{GHG}_{\mathbf{dLUC},a,y} \times \mathbf{TDF}_{y} \times \mathbf{PAF}_{a,p,y}$$

Description		Unit	Source
$EF_{dLUC,a,p,y}$	dLUC emission factor for LMU or harvested area *a*, by product type *p*, in year *y*, by GHG	(tonnes GHG per product)	Calculated
$GHG_{dLUC,a,y}$	GHG emissions from direct land use change in LMU or harvested area *a*, in year *y*, by GHG (see section 17.2.2)	(tonnes GHG)	Calculated (eq. 17.5)
TDF_y	Time discounting factor for year *y* of the assessment period (see section 17.2.3)	(dimensionless)	Default value (table 17.4)
$PAF_{a,p,y}$	Product allocation factor for LUM or harvested area *a*, by product type *p*, in year *y* (see section 17.2.4 on mass, economic or area-time allocation methods)	(dimensionless)	Calculated
a	Land management unit (LMU) or harvested area		Subcategory
p	Product or material type		Subcategory
y	Year in the assessment period		Subcategory

Equation 17.4 Land use change emission factors based on sLUC metrics

$$\mathbf{EF}_{\mathbf{sLUC},a,p,y} = \mathbf{GHG}_{\mathbf{sLUC},a,y} \times \mathbf{TDF}_{y} \times \mathbf{PAF}_{a,p,y}$$

Description		Unit	Source
$EF_{sLUC,a,p,y}$	sLUC emission factor for sourcing region or jurisdiction *a*, by product type *p*, in year *y*, by GHG	(tonnes GHG per product)	Calculated
$GHG_{sLUC,a,y}$	GHG emissions from statistical land use change in sourcing region or jurisdiction *a*, in year *y*, by GHG (see section 17.2.2)	(tonnes GHG)	Calculated (eq. 17.5)
TDF_y	Time discounting factor for year *y* of the assessment period (see section 17.2.3)	(dimensionless)	Default value (table 17.4)
$PAF_{a,p,y}$	Product allocation factor for sourcing region or jurisdiction *a*, by product type *p*, in year *y* (see section 17.2.4 on shared responsibility or product expansion allocation methods)	(dimensionless)	Calculated (eq. 17.7, 17.8)
a	Sourcing region or jurisdiction		Subcategory
p	Product or material type		Subcategory
y	Year in the assessment period		Subcategory

17.2.1 Determining the assessment period for recent land use change

Companies should use a 20-year timeframe when accounting for LUC emissions in a given year using dLUC or sLUC metrics. The assessment period for the calculations starts from the reporting year and is retrospective, as described in section 7.2.3 in chapter 7.

However, if products have a longer crop cycle or rotation period, a longer assessment period should be used. Once all LUC events have been identified and their impact accounted for, the emissions are distributed across time. See table 17.3 for guidance on how to determine the assessment period based on crop cycle or rotation periods for each product.

Table 17.3 Determining assessment period based on crop cycle or rotation periods

Product harvest cycle	Assessment period	Example
Shorter than or equal to 20 years	20 years	A company has purchased soybeans from an area that experienced LUC during the past decade. Because soy is an annual crop, the company uses the default assessment period of 20 years when calculating LUC emissions.
Longer than 20 years	Equal to harvest cycle	A company has purchased palm oil that has a production cycle of 25 years. When distributing the LUC impacts across time, 25 years is used as the timeframe. The GHG emissions are then allocated using mass allocation across the total crop cycle (hectare-cycle). Other allocation methods than mass (e.g., economic allocation) can be used when justified, and allocation methods are discussed in further detail below.

17.2.2 Estimating land use change emissions

GHG emissions from land use change are primarily due to CO_2 emissions from land carbon stock changes in biomass, dead organic matter and soil carbon that occur upon conversion and over the assessment period. Land use change GHG emissions also include CH_4 and N_2O emissions from biomass burning, and N_2O emissions associated with nitrogen mineralization of soil organic matter in mineral soils and drained peatlands, as shown in equation 17.5. Calculation guidance on estimating other GHG emissions from land use change can be found in chapter 19 (see equations 19.13, 19.16 and 19.19).

Equation 17.5 GHG emissions from land use change

$$CO_{2\,LUC} = \Delta C_{LUC} \times \frac{44}{12} \times -1$$

$$CH_{4\,LUC} = CH_{4\,BB} \times GWP_{CH_4}$$

$$N_2O_{LUC} = \left(N_2O_{BB} + \left(\left(N_2O_{OS} + \left(F_{SOM} \times EF_1 \right) \right) \times \frac{44}{28} \times 10^{-3} \right) \right) \times GWP_{N_2O}$$

Description		Unit	Source
GHG_{LUC}	GHG emissions from land use change, by GHG	(tonnes CO_2-eq per year)	Calculated
ΔC_{LUC}	Carbon stock change associated with land use change	(tonnes C per year)	Calculated (eq. 17.6)
GHG_{BB}	GHG emissions from biomass burning during land use change, by GHG	(tonnes GHG per year)	Calculated (eq. 19.19)
GWP_{GHG}	100- year global warming potential, by GHG	(tonnes CO_2-eq per tonnes GHG)	Default value
N_2O_{OS}	Direct N_2O-N emissions from land use change on drained organic soils	(kg N_2O-N per year)	Calculated (eq. 19.16)
F_{SOM}	Amount of N mineralized in mineral soils as a result of soil carbon loss through land use change	(kg N per year)	Calculated (eq. 19.13)
EF_1	Emission factor for N_2O emissions from N inputs	(kg N_2O-N per kg N input)	Default value
44/12	Conversion from C to CO_2		Constant
44/28	Conversion from N to N_2O		Constant

Carbon stock changes associated with land use change are estimated based on the difference between the carbon stock of the previous land use and the carbon stocks of the current land use, as illustrated in equation 17.6. Data on the land area that experienced land use change should include all land areas within the relevant spatial boundary that experienced land use change during the assessment period. Where available, annual data on the area experiencing land use change should be used to determine the total area experiencing land use change throughout the assessment period. When estimating carbon stock changes over a given land use change strata, carbon stock estimates may be stratified or categorized by climate, ecological zone, soil type, management practices or other potential factors impacting carbon stocks within a given land use change strata. Box 17.1 outlines one pilot testing consideration for this Guidance to develop default values that can be applied to support land use change emission estimates.

Equation 17.6 Carbon stock change from land use change

$$\Delta C_{LUC} = A_{LUC} \times (C_{After} - C_{Before})$$

$$\Delta C_{LUC,a,y} = \sum_{s} A_{LUC,s,a,y} \times (C_{After,s,a} - C_{Before,s,a})$$

Description		Unit	Source
$\Delta C_{LUC,a,y}$	Carbon stock change associated with land use change in assessment area *a,* during year *y* of the assessment period	(tonnes C)	Calculated
$A_{LUC,s,a,y}$	Area experiencing land use change of LUC strata *s*, in assessment area *a*, during year *y* of the assessment period	(ha)	User input
$C_{After,s,a}$	Carbon stock after land use change in LUC strata *s*, in assessment area *a*	(tonnes C per ha)	User input or default value
$C_{Before,s,a}$	Carbon stock before land use change in LUC strata *s*, in assessment area *a*	(tonnes C per ha)	User input or default value
s	Land use change (LUC) strata		Subcategory
a	Area of assessment (e.g., harvested area, land management unit, sourcing region or jurisdiction)		Subcategory
y	Year in the assessment period		Subcategory

Box 17.1 Default values for carbon stocks

Pilot testing consideration

We invite pilot testing companies to provide feedback on whether the Guidance should develop more detailed calculation guidance to provide default values by carbon pool, ecological zone, and continent, drawn from IPCC AFOLU sector accounting guidance (2003/2006/2019), national GHG inventories, and other recent academic articles, based on feedback during pilot testing.

17.2.3 Distributing land use change emissions over the assessment period

Past emissions must be treated consistently across time using the default 20-year (or longer, as in table 17.3) assessment period for recent LUC emissions. Companies must choose the relative distribution of these impacts across the assessment period.

Companies may either a use a linear or equal discounting approach as further discussed in chapter 7. Linear discounting addresses the shortcomings of an equal discounting method – avoiding the effects of an abrupt stop towards the end of the assessment period. Instead, it accounts for a gradual "improvement" over time across supply chains being responsibly managed. It assigns the bulk of LUC responsibility to activities more closely following a land-use change event and gradually assigns less impact as the LUC events recede into the past. Linear discounting can be assessed annually or periodically throughout the assessment period (e.g., with data every 2-3 years). This allows a more detailed overview as to why and where LUC occurs across time, including information on drivers, causes and insights on how to address them.

When using linear discounting to distribute LUC impacts over time, companies need to first identify which year is being assessed in relation to when a LUC event occurred. This enables impacts to be distributed to the year under consideration by applying the relevant time discounting factor shown in table 17.4.

Table 17.4 Emissions fraction distributed to year since land use change event (total = 100%)

Year(s) between LUC event and assessment	Time discounting factor – Linear discounting (%)	Time discounting factor – Equal discounting (%)
1	9.75%	5%
2	9.25%	5%
3	8.75%	5%
4	8.25%	5%
5	7.75%	5%
6	7.25%	5%
7	6.75%	5%
8	6.25%	5%
9	5.75%	5%
10	5.25%	5%
11	4.75%	5%
12	4.25%	5%
13	3.75%	5%
14	3.25%	5%
15	2.75%	5%
16	2.25%	5%
17	1.75%	5%
18	1.25%	5%
19	0.75%	5%
20	0.25%	5%

The linear discounting approach has several practical implications for companies. See table 17.5 for a summary of these implications.

Table 17.5 Practical implications of linear discounting

Implication	Further explanation
Company working with deforestation-free certifications, commitments, or policies benefits from linear discounting	Companies working with deforestation-free certifications, commitments, or policies will find linear discounting more favorable as more emphasis is put on more recent years compared with earlier years. Therefore, linear discounting provides more "benefits" if actions (e.g., sourcing decisions) are taken in more recent years. For more guidance on the links between certification and corporate GHG accounting, see section 17.2.3, and chapters 7 and 16.
Company setting GHG reduction targets benefits from linear discounting	Linear discounting weighs each year's impact at 0.5% more than the previous year. This means that recent years receive more weight compared with earlier years, and more recent improvement actions receive more "benefits." This can be important for planning, particularly against short-term targets.
Linear discounting provides better insights for sourcing decisions in countries or areas with very recent or ongoing deforestation	Linear discounting weighs very recent deforestation in countries or areas more heavily than equal discounting. Under equal discounting, very recent LUC impacts would be "diluted" if averaged equally over 20 years.

17.2.4 Allocating land use change emissions by products

After GHG emissions from land use change are estimated and discounted across the years in the assessment period, they must be allocated to products produced within the area under assessment. Where companies have traceability to a sourcing region or jurisdiction of origin they may apply sLUC allocation approaches. Where companies have physical traceability to a land management unit they may apply dLUC application methods.

Allocation for Statistical Land Use Change

As described in chapter 7 and table 17.2, there are two possible sLUC allocation approaches: shared responsibility and product expansion. Equations 17.7 and 17.8 show how to calculate the product allocation factor in each case. Note that in the shared responsibility allocation approach all products produced in the assessment area are included in the analysis and allocated a share of sLUC emissions. For the product expansion allocation approach, only products whose area has expanded in the assessment area are included in the analysis and allocated a share of sLUC emissions. Product allocation factors should be developed for each year during the assessment period and applied to develop sLUC emission factors following equation 17.4. Box 17.2 outlines a pilot testing consideration to include a third approach for allocating LUC emission to products based on spatially explicit allocation.

1 **Equation 17.7 Shared responsibility allocation**

$$PAF_{SR,a,p,y} = \frac{A_{H,a,p,y}}{\sum_p (A_{H,a,p,y})}$$

Description		Unit	Source
$PAF_{SR,a,p,y}$	Product allocation factor using the shared responsibility method in assessment area *a*, for product *p*, in year *y* of the assessment period	(dimensionless)	Calculated
$A_{H,a,p,y}$	Total harvested area in assessment area *a*, for product *p*, in year *y*	(ha)	User input
a	Area of assessment (e.g., sourcing region or jurisdiction)		Subcategory
p	Product or material type		Subcategory
y	Year in the assessment period		Subcategory

Note: All products *p*, that were harvested in assessment area *a,* in the year *y*, should be included in the analysis.

2 **Equation 17.8 Product expansion allocation**

$$PAF_{SR,a,p,y} = \frac{A_{H,a,p,y} - A_{H,a,p,y-1}}{\sum_p (A_{H,a,p,y} - A_{H,a,p,y-1})}$$

Description		Unit	Source
$PAF_{SR,a,p,y}$	Product allocation factor using the shared responsibility method in assessment area *a*, for product *p*, in year *y* of the assessment period	(dimensionless)	Calculated
$A_{H,a,p,y}$	Total harvested area in assessment area *a*, for product *p*, in year *y*	(ha)	User input
$A_{H,a,p,y-1}$	Total harvested area in assessment area *a*, for product *p*, in the year prior *y-1*	(ha)	User input
a	Area of assessment (e.g., sourcing region or jurisdiction)		Subcategory
p	Product or material type		Subcategory
y	Year in the assessment period		Subcategory
y-1	Year prior to the year in the assessment period		Subcategory

Note: Only products *p*, whose area has expanded in assessment area *a,* from the year prior to the year being assessed, should be included in the analysis (i.e., products where $A_{H,a,p,y} - A_{H,a,p,y-1} > 0$).

3 **Box 17.2 Spatially explicit sLUC approaches**

Pilot testing consideration

Both the shared responsibility and product expansion methods use statistical data to estimate and allocate LUC emissions in a sourcing region or jurisdiction to products produced within that spatial boundary. For many sourcing regions or jurisdictions, spatially explicit land use data on the annual area planted or harvested area by product type is not readily available for all lands and product types within the spatial boundary.

Where spatially explicit data and maps are available, they can be used to estimate LUC and allocate LUC emissions in a sourcing region or jurisdiction to products. A spatially explicit approach could estimate and allocate LUC emissions in a sourcing region or jurisdiction based on the post-conversion land use on the subset of areas that experienced land use change during the assessment period, similar to dLUC estimates.

We invite pilot testing companies to pilot such an approach to sLUC where spatially explicit data are available and to provide feedback on how such methods performs relative to the shared responsibility and product expansion allocation approaches described above. We also welcome feedback from reviewers on the tradeoffs and implications of such an approach.

Allocation for Direct Land Use Change

Direct land use change emissions must be distributed according to the multiple outputs of a production system. During the assessment period, a given field may have been used for cattle, wood production, as well as cocoa cultivation, raising the question of how much of the overall LUC impact should be attributed to each product.[10]

There are different methods to allocate emissions across products, as demonstrated in table 17.6.

Table 17.6 Methods to allocate land use change emissions across products

Allocation method	Explanation
Economic allocation	Rising demand for land-based products leads to agricultural land expansion and LUC, so economic allocation across products reflects this causal relationship. For this allocation method, the economic value of each agricultural or forestry product must be known or estimated. In some cases, additional judgment calls will be needed. For example, if land is used for coffee (sold on the market) and also cassava (for farmers' consumption), then how is the value of these different products defined? Another judgment call is whether to allocate based on the total sale price or by profit margin. Price variability requires decisions about what prices to use. Because the economic allocation method reflects what is in most cases the primary driver for deforestation, it is recommended as the default choice.
Mass allocation	This method allocates the GHG emissions based on the mass (e.g., per kilogram) of each of the products of the production system in question. For example, a company owns a farm that produces coffee and cassava. When applying mass allocation, the same GHG emission impact will be allocated to 1 kg of coffee as to 1 kg of cassava. Note that mass allocation results can be significantly different depending on whether one uses wet or dry mass. If mass allocation is applied, whether it is based on dry or wet content should be explicitly stated. Note that mass allocation is often used when a single product is produced, assuming the same value to each kilogram of product. In the case of a single product, mass allocation and economic allocation give the same result.
Allocation by area-time	This method allocates the same GHG emission impact to each square meter-year (m^2a) of the piece of land where the land-based product is grown. Allocation by area-time is a simpler method. However, this allocation method is not useful if there are years where the land in question does not produce anything. In this case, an impact is allocated although

[10] Note that Chapter 16 deals more generally with emissions allocation issues (which recur in multiple chapters across this guidance), but the guidance in this chapter is specifically relevant to land use change.

	nothing is produced. Also, the area-time approach has limited relevance when the yield varies, especially if due to natural causes (e.g., amount of rainfall, temperature). This approach is also limited in the case where a piece of land is used for multiple crops and one of the crops has a very high value while another has a low value. Allocating the same GHG emission impact for both crops might not reflect the fact that one crop was the primary driver for deforestation.

In most agricultural and forestry systems, market demand determines production. In an open market, prices significantly influence production. It is therefore best to allocate impact within agriculture and forestry systems based on the economic value of their output, unless a better rationale can be presented (e.g., mass or area-time), as demonstrated in table 17.6.

Economic allocation requires price data at the farm level for all the farm's outputs. The price data used should reflect the average price during the period under consideration. This is in line with the yield data used, which also represent the average yield during the period under consideration. The following data should be collected:

- Total production in time period (e.g., kilograms)
- Price per kg
- Revenue
- Allocation method
- dLUC emissions (in CO_2e/20 years)

The limitation of the economic allocation method is that it assumes that the various actors in the production system act rationally (e.g., prefer to pay less for more products). Yet, where prices vary, economic allocation assigns a higher GHG emission to those paying more. An average market value rather than buyer-specific values could be used if this differentiation is not desired. Companies should maintain transparency by reporting which approach is used.

Economic allocation works well when price is a key driver for a producer's decision-making, as it informs which agricultural or forestry products are produced on the land. Economic allocation can also be applied to situations where there was only one product grown on the land over the 20-year period. In this case, the average crop price should be used to account for price variation over time; this ultimately leads to the same result as mass allocation. At a farm level, ideally the farmer's net income is used. If this is unknown, then the crop's market value can be used. However, in cases where the price plays only a minor role in such decisions (e.g., state-controlled production), other allocation approaches can be applied.

Hierarchy of allocation across products and time

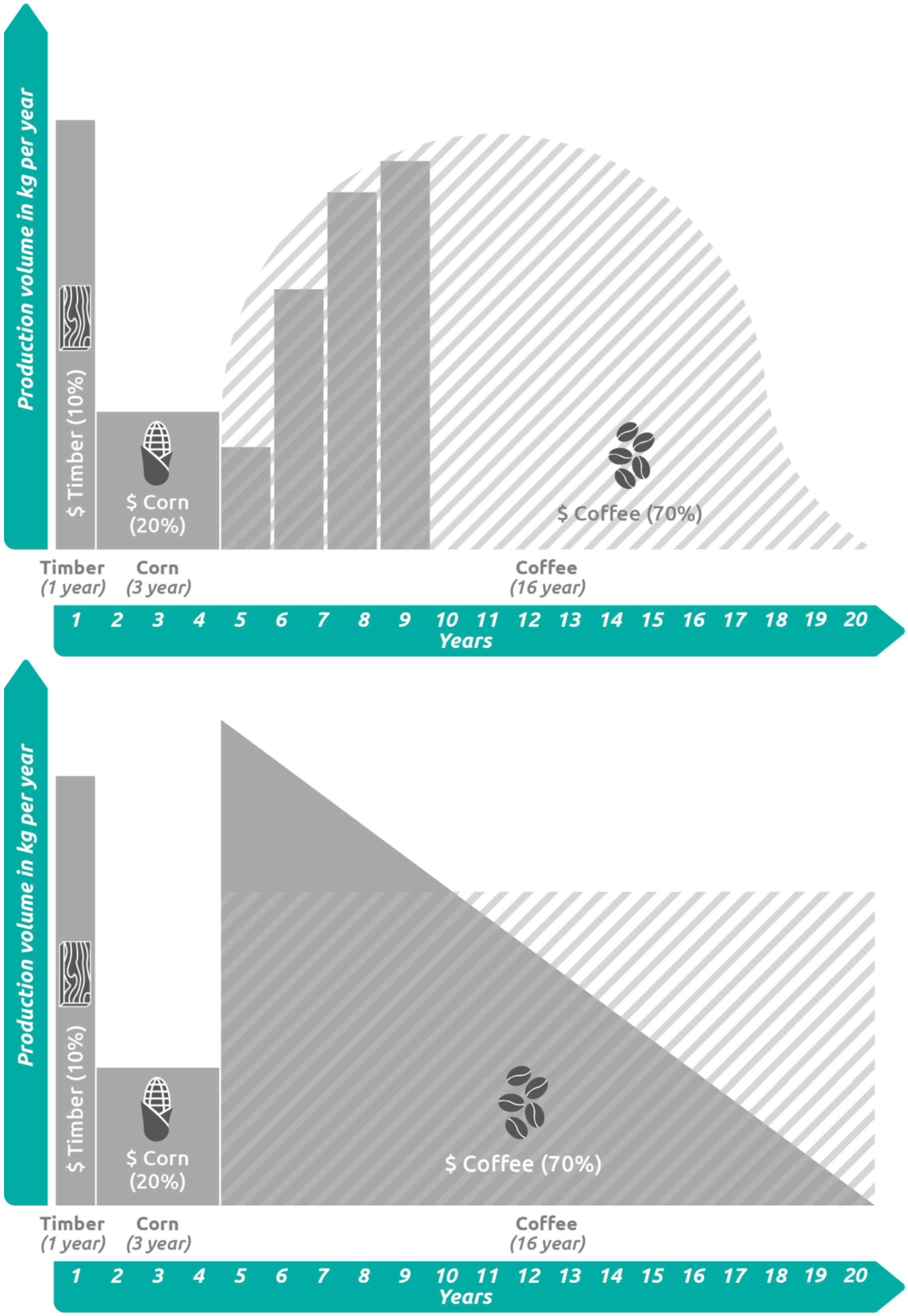
Certain production systems may grow multiple crops together in a given field; others might rotate crops over time. In these types of situations, it is best to first allocate LUC emissions across products using the economic allocation method before discounting emissions across time using an output-specific attribution. This is consistent with LCA methods and makes calculation simpler. It is also relevant for farm-level assessments. Depending on the knowledge companies have of the production system and its characteristics, they can use one of two approaches to discount impacts across time, as described in table 17.7.

Table 17.7 Hierarchy of allocation across products and time

Type of production yield data available	Allocation approach
Variable production yield data (year-by-year) is available	Commodities like cocoa or coffee usually have variable yields (e.g., high productivity at the start vs. low productivity towards the end of the production cycle). If this information is available, companies should apply economic allocation across the different products and then within the cocoa or coffee production system apply equal allocation per kilogram of product (not per year). In a way, mass is used as a proxy for price. Here, natural variations of yield should be neglected, while variations that are due to land management practices should be taken into account.
Average production yield data is available and used as a proxy	If the variable yield is not known and an average production yield is assumed, then companies should apply economic allocation across the different products and then discount emissions within the production system (e.g., cocoa, coffee) over time (see table 17.4).

Figure 17.1 further illustrates the differences between the two allocation approaches, showing the accounting approach if variable annual yield data is available versus if only average annual yield data is available. This figure—which is relevant to all tree-based crops—shows the case of a hypothetical piece of land that has been producing coffee for most of the past 20 years, but where the timber was initially sold when the land was cleared in the first year, and where corn was produced for three years before the coffee was planted. Over the 20-year period, in this example, 10% of the total income came from timber, 20% from corn, and 70% from coffee.

1 **Figure 17.1 Illustration of farm level production system with variable yield data and average yield data**



2 *Source:* Adapted from Quantis (2019), p.41.

17.3 Calculation approaches for land tracking metrics

This section describes the various approaches to calculate land tracking metrics.

17.3.1 Indirect Land Use Change Emissions

While direct land use change can be physically observed within specific supply chains (e.g., on a farm or land management unit), indirect land use change emissions must instead be modeled. There are several approaches for developing iLUC emission factors, whether "biophysical-only" or using econometric models that estimate changes in demand for products based on economic relationships. Schmidt et al. (2015) explain six main distinctions among iLUC models, identifying differences in addressing or accounting for:

- Causal relationships between the demand for land (or land-based products) and deforestation
- Geographical boundaries
- Temporal issues
- Land productivity
- Crop intensification and/or reduced product consumption
- Inclusion of crop and biofuel iLUC effects in life cycle inventories

As described in chapter 7, several government and corporate initiatives have incorporated measurement of biofuel-related iLUC emissions in recent years. These initiatives may have iLUC emission factors that companies can use. For example, the California Air Resources Board (CARB)'s Low Carbon Fuel Standard uses the Global Trade Analysis Project (GTAP) model, and their 2015 report[11] includes emission factors for each of the six main feedstock types per unit of energy produced. Emissions can be calculated by multiplying the emission factor by the quantity of product (or quantity of energy) produced or purchased, as illustrated in equation 17.9.

Equation 17.9 Indirect land use change emissions

**Indirect land use change emissions (t CO_2e) =
iLUC factor (t CO_2e per t produced OR g CO_2e per MJ energy produced) x
quantity of product produced or purchased (t OR MJ energy)**

t	=	Tonnes
CO_2e	=	Carbon dioxide equivalent
iLUC	=	Indirect land use change emissions
g	=	Grams
MJ	=	Megajoules

Indirect land use change occurs at a national and global level where the demand for more land-based products (e.g., biofuels) can lead to additional products being produced on land that would have otherwise served a different purpose (e.g., food production). This demand increase can lead to displacement and land conversion (e.g., deforestation), and can occur across national borders. When estimating iLUC where the country of origin is known, one approach to account for both national and global effects is to develop the iLUC estimate using an average factor (i.e., 50% using the global emission factor and 50% using the country-level emission factor).

[11] California Air Resources Board, 2015

17.3.2 Carbon Opportunity Costs

Carbon opportunity cost (COC) factors are calculated by estimating the carbon previously lost on lands used to produce a given product, and dividing the lost carbon by total production of that product. Equation 17.10 illustrates how to calculate the undiscounted COC factor. Because carbon losses occur quickly but production of food or other land-based products can continue for many years, the COC factor is then often annualized by using a discount rate or dividing by an amortization period. For example, Searchinger et al. (2018) use a default discount rate of 4 percent, effectively annualizing the carbon opportunity cost over an amortization period of 34 years (i.e., dividing the total historical carbon loss by 34), which is similar to the approach used in U.S. biofuel policy analysis (e.g., Lark et al. 2022).

Equation 17.10 Carbon opportunity cost factor

$$\text{COC factor (t } CO_2e \text{ per t produced)} = \frac{\text{Native carbon stock } [\frac{tC}{ha}] - \text{Productive carbon stock } [\frac{tC}{ha}]) \times (44/12)}{\text{total production quantity (t)}}$$

COC	=	Carbon opportunity cost
t	=	Tonnes
CO_2e	=	Carbon dioxide equivalent
tC/ha	=	Tonnes of carbon per hectare
44/12	=	Ratio of the molecular weight of carbon dioxide to that of carbon

Note: The Carbon opportunity cost value is discounted over time.

To estimate native carbon stocks, dynamic global vegetation models (e.g., those included in The Inter-Sectoral Impact Model Intercomparison Project[12]) and/or biome-level average reference values (e.g., Tier 1 estimates given in IPCC 2006) can be used. Default values from IPCC or carbon stock data from national GHG inventories can be used to estimate existing (productive) carbon stocks. Further methods for estimating carbon stocks are described in chapters 8 and 18.

Like the other metrics in this chapter, COC factors can be calculated at global, regional, national or even farm-level scales. A global COC factor assumes that rising demand for a given product, regardless of where it is sourced, will result in an expansion in land use to produce that product somewhere in the world at a carbon cost equivalent to the global average historical carbon loss per hectare associated with it. A smaller-scale COC factor uses more local data on native and current carbon stocks, and yields, to determine the COC factor. Because of the global nature of markets for most land-based products, one may use multiple geographic scales to show a range of COC estimates, or use an average of a global and a smaller-scale estimate.[13] COC is rarely zero, especially when assessed at a global, regional, or national level, because there is nearly always a carbon opportunity cost to using land for agriculture, forestry, or other land-based (e.g., energy) products, versus leaving the land in its natural state (or allowing it to return to its natural state). In rare instances at finer geographic scales—for example, conversion of native grassland to tree plantations, or irrigated crops in a desert—the carbon opportunity cost may be negative.

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[12] Available at www.isimip.org

[13] Wirsenius et al., 2020

In its most basic form, the COC calculation only requires the annual quantity of crops or livestock products that are produced or purchased. These can then be multiplied by global or more spatially explicit COC factors, as in equation 17.11.

Equation 17.11 Carbon opportunity costs

$$\text{COC (t } CO_2\text{e)} = \text{COC factor (t } CO_2\text{e per t produced)} \times \text{quantity of product produced or purchased (t)}$$

COC	=	Carbon opportunity cost
t	=	Tonnes
CO_2e	=	Carbon dioxide equivalent

COC estimates should be reported separately from dLUC and iLUC estimates, and scope 1, 2 and 3 emissions, to avoid any double counting. For example, emissions from land cleared in the past 20 years to produce beef sourced by a company would appear both in that company's dLUC estimate as well as in a COC estimate. In addition, management practices that increase soil carbon stocks could appear both in land management emissions (chapters 8 and 18) as well as a reduction in carbon opportunity costs. That said, overlap between COC and dLUC is not inevitable; for example, if a company was sourcing all products from areas deforested more than 20 years ago, it could estimate a dLUC of zero but would still have carbon opportunity costs.

COC calculator: Searchinger et al. (2018) include global-level COC factors for more than 60 food and feed products in a "Carbon Benefits Calculator".[14] This metric, as well as the other metrics in this chapter, can also be useful for intervention accounting to help inform company decision-making. At the time of publication, COC estimates are not yet established for forestry products.

Box 17.3 presents an example of how using carbon opportunity costs in intervention accounting can inform decision-making.

[14] Available at https://www.wri.org/carbon-benefits-index

Box 17.3 Using carbon opportunity costs in intervention accounting to inform decision-making

This box provides calculations with carbon opportunity costs for a hypothetical company in West Africa that is currently growing 1,800 tonnes of unfertilized maize per year across 1,000 hectares (as described in Chapter 11, Box 11.3). The company wants to increase its business by producing 4,500 tonnes of maize per year. It is exploring two options to increase its maize production: intensifying production on its existing land holdings by adding nitrogen fertilizer, or acquiring additional lands for maize production at current yields. The company explores three scenarios:

Baseline scenario: The unfertilized fields yield 1.8 t/ha/year of maize or 1,800 t/year of maize overall. The company estimates its scope 1 (agricultural production) emissions of 0.06 t CO_2e per t of maize, or a total of 108 t CO_2e/year. It also estimates annualized carbon losses (relative to native forest) on its croplands at 5.5 t CO_2e/ha/year, for a total carbon opportunity cost of 5,500 t CO_2e/year.

Scenario 1 (intensification): The company estimates that adding 100 kg N/ha/year of fertilizer would increase yields to 6 t/ha/year, meaning that production of the 4,500 t of maize would require only 750 hectares – reducing land demand by 250 hectares. Scope 1 emissions (due to increased fertilizer production and use) would rise to 0.30 t CO_2e per t of maize, or 1,350 t CO_2e, an increase of 1,242 t CO_2e from the baseline scenario. Carbon opportunity costs, which are related to total land occupation, would fall to 4,050 t CO_2e, a decrease of 1,450 tonnes CO_2e. Therefore, while scope 1 emissions would increase, the carbon opportunity costs would decrease by more than the scope 1 emissions increase, and net GHG benefit would be 208 t CO_2e relative to the baseline scenario.

Scenario 2 (expansion): The company estimates that it would need to acquire an additional 1,500 hectares of farmland to expand production to 4,500 t of maize at current unfertilized yields. In this case, scope 1 emissions would slightly rise to 270 t CO_2e/year, an increase of 162 t CO_2e/year. However, the large increase in land occupation would increase carbon opportunity costs to 13,950 t CO_2e/year, an increase of 8,450 t CO_2e/year.

By assessing both its scope 1 agricultural production emissions and its annualized carbon opportunity costs, the company decides to pursue the intensification option (Scenario 1) to realize its maize production goal, since Scenario 1 has net GHG benefits compared to both the baseline scenario and the expansion option (Scenario 2).

	(a) Total land occupation (ha)	***(b)*** Crop yield (t/ha)	***(c)*** Total maize produced (t) ***(c = a x b)***	***(d)*** Scope 1 agricultural production emissions per t of maize (t CO_2e/t maize produced)	***(e)*** Scope 1 agricultural production emissions (t CO_2e) ***(e = c x d)***	***(f)*** Annualized carbon losses on maize cropland vs. native vegetation (t CO_2e/ha)	***(g)*** Carbon opportunity costs per t of maize (t CO_2e/t maize produced) ***(g = f / b)***	***(h)*** Carbon opportunity costs (t CO_2e) ***(h = c x g)***	***(i)*** Scope 1 agricultural production emissions + carbon ***(i = e + h)***
Baseline scenario	1,000	1.8	1,800	0.06	108	5.5	3.1	5,500	5,608
Scenario 1 (intensification)	750	6.0	4,500	0.30	1,350	5.5	0.9	4,050	5,400
Scenario 2 (expansion)	2,500	1.8	4,500	0.06	270	5.5	3.1	13,950	14,220
Net effect of scenario 1 relative to baseline scenario	Land occupation reduced by 250				Scope 1 emissions increase of 1,242			COC reduced by 1,450	Positive impact of 208 (Implement action)
Net effect of scenario 2 relative to baseline scenario	Land occupation increase of 1,500				Scope 1 emissions increase of 162			COC increase of 8,450	Negative impact of 8,612 (Do not implement action)

Note: Example adapted from Searchinger et al. (2018), using yield response assumptions from Fischer et al. (2014), Scope 1 production emission factors from Bryngelsson et al. (2016), and carbon opportunity costs (including estimates of carbon in native vegetation) from Searchinger et al. (2018). All metrics are per year.

17.3.3 Land Occupation

When using statistical data to estimate total land occupation related to a company's operations and/or value chain, the general approach is to divide activity data (e.g., production in tonnes) by yield factors (e.g., tonnes per hectare) to estimate the amount of land required annually, as demonstrated in equation 17.12.

For food, feed, and energy feedstocks, global and national average yields are readily available from online data repositories such as FAOSTAT[15] or LCA databases or meta-analyses (e.g., Poore and Nemecek 2018).

The most basic application of this method would use any publicly available average global yield for a given land-based product. This is relatively straightforward for most food, feed, and feedstock crops. More specific yield information covering regional-, national-, or farm-level can also be used.

Equation 17.12 Land occupation for agricultural products

$$\text{Land Occupation for Agricultural Products (ha)} = \frac{\text{Quantity of product produced or purchased (t)}}{\text{Yield of that product }\left(\frac{t}{ha}\right)}$$

ha = Hectares

t = Tonnes

For example, if a company sourced 100,000 tons of wheat in 2020, with a yield of 5.3 tons per hectare, the estimated land occupation of the wheat would be 10,000 / 5.3 = 18,868 hectares in 2020.

For wood products, however, the amount of wood per hectare harvested that is used for any number of products is more difficult to determine through readily available data. A rough calculation is possible at the national level.

If the country of origin is known, FAOSTAT provides the total amount of wood that goes into various products for each country. A study by Wageningen University[16] using the IMAGE model gave estimates of average industrial roundwood harvests per hectare for a number of countries and regions and could be used as a starting point. Table 17.8 shows these average wood harvest values.

Table 17.8 Estimates of industrial roundwood harvests per hectare

Region or country	Wood volume cut down/ha (m^3/ha)		Wood volume removed/ha (m^3/ha)		Implied slash rate	
	Tree plantation	**Clear cut**	**Tree plantation**	**Clear cut**	**Tree plantation**	**Clear cut**
Brazil	343	127	273	109	20%	14%
Canada		238		190		20%

[15] Available at https://www.fao.org/faostat/en/#data

[16] Arets et al., 2011

Central America	295		246		17%	
Central Asia		202		140		31%
China	113	111	93	71	18%	36%
Eastern Europe		281		205		27%
India	257	69	214	58	17%	16%
Indonesia	241	125	197	104	18%	17%
Japan		154		125		19%
Northern, Western, and Eastern Africa	390		312		20%	
Oceania	501	40	393	33	22%	18%
Russia		155		107		31%
South America (ex. Brazil)	409	231	295	166	28%	28%
South Korea	113	111	93	71	18%	36%
Southeast Asia	146	155	120	129	18%	17%
Southern Africa	216		172		20%	
Turkey	173	227	121	151	30%	33%
Ukraine		202		140		31%
United States of America	306	357	247	279	19%	22%
Western Europe	173	422	121	326	30%	23%

Note: values are for the year 2005. Blank cells mean no value was given in the study.
Source: Adapted from Arets et al. (2011), Table A2.2.

Companies should estimate the "clear-cut equivalent" area required to produce what they purchased, as illustrated in equation 17.13. This is calculated by using estimates for aboveground wood density per hectare ("wood volume removed" in table 17.8) and an estimate of the percentage of timber harvests that become slash (i.e., wood cut down but not removed from the forest). Clear-cut equivalent is used to avoid unfairly penalizing selective harvesting when using this metric as, for a given level of wood harvest, the area needed is higher for selective harvesting than for clear cutting. The amount of wood harvest should also include harvests from thinning operations.

If a company purchasing wood products has traceability with their suppliers, it might be possible to work with the suppliers to estimate the average wood density of the land and the average slash rate associated with the harvest.

If the country of origin is not known, and value chain traceability is limited, companies can determine the average wood density in all countries or regions where the product is likely to have come from, and use a default slash rate (usually between 20-40%), using the data in table 17.8. Life cycle impact assessment methods, models, and databases can also be used to estimate land occupation associated with production and extraction of wood products.[17]

Equation 17.13 Land occupation for wood products

$$\text{Land Occupation for Wood Products (ha)} = \frac{\text{Quantity of wood products produced or purchased [m3]}}{\text{Above-ground wood density at harvest }\left[\frac{m3}{ha}\right] \times (1\text{-}\%\text{ slash})}$$

ha	=	Hectares
m3	=	Cubic meters
m3/ha	=	Cubic meters per hectare
% slash	=	Percentage of timber harvest that became slash (i.e., wood cut down but not removed from the forest)

For example, if a company harvested 1,000,000 m^3 of wood in 2019, with an aboveground density of 300 m^3 per hectare and a slash rate of 30%, the estimated land occupation would be 1,000,000 / (300 * 70%) = 4,762 hectares of harvested clear-cut equivalent in 2019.

[17] Allacker et al., 2014

Land Management Carbon Calculation Guidance

Chapter 18: Land Management Carbon Calculation Guidance

This chapter provides calculation guidance on quantifying land management net CO_2 emissions and removals across land uses remaining in the same land use from a scope 1 and scope 3 perspective. This chapter provides guidance on quantification methods by biomass, dead organic matter and soil carbon pools to estimate annual net carbon stock changes using stock-change accounting. It also provides guidance on methods to account for gross biogenic land CO_2 emissions and gross biogenic land CO_2 removals using flow accounting.

Sections in this chapter

Section	Description
18.1	Introduction to calculating land management CO_2 emissions and removals
18.2	Stock-change accounting methods
18.3	Flow accounting methods

18.1 Introduction to calculating land management net CO_2 emissions and removals

This section provides an overview of challenges and methods to account for land carbon stock changes as well as guidance on evaluating uncertainty in data.

18.1.1 Challenges for land carbon accounting

Accounting for land carbon stock changes across land uses and carbon pools in an inventory is complex. Challenges include a range of issues from data collection, accounting for variability, unequal timing of carbon stock gains vs. losses, tracing impacts back to attributable lands, etc. as outlined in box 18.1. Due to these challenges the calculation guidance below provides flexibility in the approaches to account for carbon stock changes, with guidance on ensuring increased accuracy when accounting for *Land management net CO_2 removals* in accordance with the CO_2 removals requirements (see chapters 6 and 8 for details).

Box 18.1 Key challenges for land carbon accounting

Accounting for land carbon stock changes is complicated by several factors:

- **High spatial variability**. Carbon stocks within a given landscape can be highly variable based on both natural (e.g., climate, vegetation, soil, geology, topography, etc.) and anthropogenic (e.g., land use, current management practices, historic management, etc.) factors. Because of this, it is essential to account for the spatial variability when estimating land carbon stock changes. An assessment that fails to capture spatial variation in carbon stocks—or at least the dominant ones—would likely produce highly uncertain estimates of carbon stock changes. This is especially important for regional accounting because high levels of uncertainty at local scales can amplify to larger errors at regional scales.
- **Carbon stock change depends on location**. Because land carbon stocks are so strongly influenced by climate, vegetation type, soil type, historical land use, current land use and land management

decisions, and other factors, it is important to account for these differences when estimating land carbon stock changes specific to lands owned or controlled by a company or in their value chain. This can be done either through inventory or sampling approaches to estimate land carbon stocks within a given area or strata (i.e., specific to a given strata based on climate, ecological zone, soil type, land use, management practices, etc.), or with models (e.g., forest growth and yield models or soil biogeochemical models) that mechanistically represent the relationship between carbon pools and the factors influencing the rate of change specific to a given location. In either case, estimates should be calibrated against empirical measurements.

- **Rapidly lost, slow to increase**. Biomass and soil carbon pools experience carbon stock losses at different rates from carbon stock gains. Carbon stocks can decrease due to a single event such as a harvest event, natural disturbance or soil cultivation. Meanwhile, gains in land carbon stocks increase at more modest rates over time due to biomass growth or gradual accumulation of soil carbon. Similarly, the rate of carbon stock changes can often be rather small relative to the total carbon stocks, spatial variability in carbon stocks or precision of methods used to estimate carbon stocks. Land carbon stock changes can also experience high temporal variability due to other factors such as yield variability and climate change impacts. The frequency of monitoring land carbon stocks should ideally balance the tradeoff between detecting both short-term annual carbon losses that may require higher levels of spatial resolution to detect and accurately measuring the gradual carbon gains across the entire spatial boundary.
- **Proximal and remote sensing methods are still developing**. Despite continued research and technological innovation, remote sensing of aboveground biomass and the associated carbon stocks still faces barriers to widespread deployment due to data availability to calibrate biomass estimates, harmonizing datasets to compare maps at multiple points in time and bias in the data (i.e., overestimating high biomass values and underestimating low values). Other carbon pools such as soil carbon cannot be directly estimated through remote sensing alone, thus requiring the use of carbon stock change factors, models, and measurement. Proximal methods for soil carbon sampling, like handheld infrared sensors, have promise but are not sufficiently developed at this time.
- **Potential for leakage**. In cases where land carbon stocks increase over time but at the expense of land productivity (e.g., crop yield), it can result in an increase in GHG emissions elsewhere if previously undisturbed land is cleared to replace the food production, resulting in carbon stock losses on lands outside the inventory boundary. Given the global demand for land use any company accounting for land management emissions or removals must also track the global impacts due to their demand for land as detailed in chapter 7. Chapter 11 provides additional guidance on estimating the global climate impacts of company's land management decisions, both negative and positive, that occur outside of the company's operations or value chain.

18.1.2 Overview of methods

This section provides a description of different methods available to estimate land carbon stock changes with detailed guidance by carbon pools including assuming no carbon stock changes, activity-based approaches, remote sensing-based approaches, model-based approaches, and measurement-based approaches.

Table 18.1 Summary of land carbon stock change accounting methods by methodological complexity

Accounting method	Methodological complexity
Assume no carbon stock changes	Tier 1
Activity-based approaches	Tier 1, 2 or 3
Remote sensing-based approaches	Tier 2 or 3
Model-based approaches	Tier 3
Measurement-based approaches	Tier 3

These methods can be classified under the IPCC Tier 1, 2 and 3 classification based on methodological complexity, as shown in table 18.1. The assumption of no carbon stock change is a Tier 1 method that can be applied under certain circumstances as described below. Activity-based approaches can be classified as Tier 1, 2 or 3 based on the data used ranging from IPCC global defaults, to country-specific or management specific factors, to factors developed using primary data from producers. Remote sensing-based approaches are considered Tier 2 or Tier 3 methods depending on whether they use regional carbon stock estimates or directly measure carbon stock change. Model-based or measurement-based approaches introduce the greatest methodological complexity and are considered Tier 3 approaches requiring primary data from producers. The combined use of different approaches may be the most promising alternative to obtain cost effective results. Remote sensing, modelling and ground measurements used in combinations can deliver accurate results with reduced uncertainty, however there is still substantial development required to deploy such methods for all geographies, land uses and carbon pools.

Assume no carbon stock change

Under certain land management practices, the carbon stocks of a given carbon pool might not be directly impacted or do not significantly change from year to year. IPCC national GHG inventory guidelines provides conservative assumptions where no change in carbon stocks can be applied for a particular land use and carbon pool. The sections below detail by carbon pool and land use where the assumption of no carbon stock change may be applied when developing a corporate GHG inventory.

Activity-based approaches

Where limited data is available on the specific lands or land management practices impacting carbon stock changes, activity-based methods can be applied to estimate annual net land carbon stock changes. These methods use activity data on land area and management practices stratified by both environmental factors (e.g., climate, ecological zone, soil type) and land management practices (e.g., land use, forest management, rotation period, soil tillage practices, soil carbon inputs, etc.). Activity data on land areas or management within a given strata can then be multiplied by relevant stock change factors or emission factors based on international IPCC default values (Tier 1) or country and management-specific values (Tier 2) to estimate carbon stocks and carbon stock changes in accordance with the Gain-Loss or Stock-Difference method. This approach relying on secondary data to estimate carbon stock changes will reduce the accuracy of the estimate relative to higher tier methods, but increased resolution of the stratification and stock change factors can be used to improve the accuracy and precision of the carbon stock change estimates (e.g., based on more detailed forest type, tree genus or species, age class or forest management practice, etc.). Given the uncertainties associated with IPCC Tier 1 and Tier 2 methods and lack of monitoring data to address permanence concerns, activity-based approaches using secondary data do not meet the requirements for accounting for and reporting *Land management net CO_2 removals* in corporate GHG inventories (see chapter 8). Many tools currently use activity-based approaches which can be useful in developing initial estimates of different land carbon stock changes to understand the relative magnitude of change and uncertainty before further investing in primary data collection to support more refined estimates of emission reductions or removals associated with specific land management practices.

Model-based approaches

Model-based approaches use mathematical modelling based on various input variables (e.g., temperature, precipitation, vegetation type, management practices, etc.) and fixed parameters (i.e., calibration factors) to estimate annual net land carbon stock changes across carbon pools. Where models are used, evidence should be provided (e.g., based on the uncertainty ranges or other statistical metrics comparing modeled vs measured values) that the underlying data are applicable to the region of interest, the model predictions are more accurate than the results derived from the activity-based methods and the predicted values do not deviate from the uncertainty ranges provided by IPCC Tier 1 estimates.

Empirical models use field measurements to develop statistical relationships between GHG fluxes and agricultural management factors. In turn, process-based (or mechanistic) models mathematically link important biogeochemical processes that control the production, consumption, and emission of GHGs. Some models may only require one or several input variables to estimate GHG fluxes; others might have extensive data requirements that span different spatial and temporal scales. Input data can be physical variables such as temperature, precipitation, elevation, and soil nutrient levels, or biological variables such as soil microbial activity and plant diversity. The accuracy of models is variable and depends on the robustness of the model, calibration of the fixed parameters to the particular application and the accuracy of the input variables. For example, if a model is used in a new agro-climate regime for which it was not previously calibrated, the model may not be reliable. Annual net land carbon stock changes estimated using model-based approaches should report the uncertainty range and regularly update the model based on resampling of measured land carbon stock changes at minimum every 5 years.

Remote sensing-based approaches

Remote sensing-based approaches can be considered a subset of model-based approaches where remote sensing data (as opposed to activity data or ground-based measurements) are used to inform model predictions of annual net land carbon stock changes. Different types of remote sensing data are available to detect land management practices, carbon stocks or both. Optical data from multispectral or hyper-spectral imagery, as well as data from active sensors that send out a signal to gather information such as light detection and ranging (LiDAR) and radio detection and ranging (radar) can be used to support remote sensing-based approaches to estimate carbon stock changes. Remote sensing technology (satellite and aerial data) can effectively cover much larger areas in comparison to measurement-based methods. It is important to note that local calibration and/or model development is required to derive predictions from the remotely sensed data.

Optical remote sensing data suffers from saturation at high biomass levels and must be combined with other data such as bioclimatic data, stand age, or forest inventory data to improve the predictive capacity. Remote sensing approaches pose more challenges to estimate changes in soil carbon stock changes however can be useful in informing the cropping systems, tillage and residue management practices as inputs to model-based approaches. Data from active remote sensing can produce more accurate predictions of carbon stock changes, but this type of data is generally more expensive to collect and requires a high level of skill and knowledge to pre-process, remove noise and process the information.

Measurement-based approaches

Repeated measures of carbon stocks for selected carbon pools (e.g., aboveground biomass, belowground biomass, deadwood, litter or soil organic carbon) within a given stratum using sampling protocols or other inventory methods can provide the most accurate method to determine annual net land carbon stock changes, depending on the sampling methods used. Measurement based approaches are typically used to estimate carbon stocks based on sampling within a given stratum that represents a relatively homogeneous land area with respect to both natural and management factors impacting carbon stocks. The number of sampling plots within a stratum and frequency of resampling plots can be determined based on the expected variance in carbon stocks within the stratum, the expected magnitude of carbon stock changes and the desired precision in the estimates.[18] Measurements should occur at similar times during the year to account for seasonal changes in carbon stocks and ensure consistency in the measurements over time. Measurement-based approaches can be labor intensive and expensive, but when combined with model-based approaches across a well- designed land stratification and sampling protocol, can allow for increased scalability. Sampling protocols may vary depending on the land use and carbon pool and commonly applied methods for collecting field data are described in section 18.2 below.

For scope 1 accounting, lands should be stratified and sampling should occur across all lands under the company's ownership and control. For scope 3, measurements should be taken at a subset of lands managed within the supply chain that are representative of the spatial boundary as determined in accordance with the requirement and guidance in chapter 8.

Hybrid approaches

There are many combinations of the approaches described above that can be used to estimate land carbon stock changes. There are an increasing number of publicly available tools (e.g., calculation spreadsheets, software and protocols) for estimating land carbon stock changes using activity-based, remote sensing-based, model-based or hybrid approaches. The GHG Protocol website provides a non-exhaustive list of such resources.[19]

Many of the more accessible and user-friendly tools that would be most amenable to use by farm and forest managers tend to implement Tier 1 or Tier 2 approaches. Process-oriented models are often unwieldy to use, although more user-friendly interfaces are available or under construction for some process models and specifically intended for use by farm managers, extension agents, and consultants. These offer the most potential for accurately calculating farm or forest-level land carbon stock changes, at least in regions for which background, calibrating datasets are available. This Guidance does not recommend specific tools for calculating GHG fluxes, companies should instead select tools that best allow them to meet their objectives for compiling an inventory and the GHG accounting and reporting principles. In evaluating individual tools, companies should consider a range of questions, including:

- Is the tool comprehensive in terms of its coverage of different emission sources, GHGs and management activities, particularly those that are practiced or planned on the given land management unit or sourcing region? And does it integrate the effects of multiple management activities across the land management unit or sourcing region?
- What input data are required and will land managers be able to provide these data?

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[18] See Measurement Guidelines for the Sequestration of Forest Carbon for more details USFS, 2007 available at https://www.fs.usda.gov/treesearch/pubs/13292

[19] Available at https://ghgprotocol.org/land-sector-and-removals-guidance

- Does the tool have access to relevant external data (e.g., weather data or soil databases)?
- How much labor and technical expertise is required to use the tool?
- Does the tool have a user-friendly interface that is aligned with corporate GHG inventory accounting categories and accessible to inventory compliers?
- Is the tool transparent about its methodology, including limitations and assumptions?
- Is the tool geographically representative? Is it tailored to the region/area of interest?
- Is the tool accurate enough to help meet the business objectives for compiling a GHG inventory? And does it provide additional functions to support business objectives beyond GHG inventory accounting?
- Is the tool up-to-date (e.g., are emissions factors updated on an annual basis)?
- Does the tool provide estimates of uncertainty?
- Does the tool have verifications functions (e.g., are ranges enforced for the values of activity data)?
- Can the tool quantify environmental impacts other than GHG fluxes (e.g., nitrate or phosphorus pollution)?
- Can the tool quantify GHG performance metrics?
- Is the tool otherwise consistent with the GHG accounting principles?

18.1.3 Evaluating uncertainty in data

Data used to estimate net carbon stock changes should be within internationally reported uncertainty ranges for carbon stocks and growth rates associated with lands in the same climate, ecological zone and soil type. The 2006 IPCC Guidelines for National GHG Inventories and 2019 Refinements for the Agriculture, Forestry and Other Land Use sector provides estimates of carbon stocks, growth rates and carbon stock change factors for biomass, dead organic matter and soil carbon pools as well as their uncertainty ranges. Secondary data used to estimate land carbon stock change should fall within the given IPCC uncertainty ranges.[20] Where data used to estimate carbon stock changes exceed established maximum carbon stocks, growth rates or carbon stock change factors within IPCC tables, measurements based on primary data should be provided to verify estimated carbon stock changes.

18.2 Stock-change accounting methods

Section 18.2 provides guidance on stock-change accounting methods companies can use to account for *Land management net CO_2 emissions or removals* based on the net land carbon stock change in biomass (section 18.2.1), dead organic matter (section 18.2.2) and soil carbon pools (section 18.2.3). This section explains how companies can apply the assumption of no carbon stock changes, activity-based approaches, remote sensing-based approaches, model-based approaches, and measurement-based approaches for each carbon pool.

18.2.1 Biomass carbon stock changes

Factors that affect biomass production or biomass stocks will also impact on carbon stocks as dry biomass consists of approximately 50% carbon. Biomass carbon stocks can change due to impacts from continuous processes (such as growth, change in vegetation development stage, decomposition), or discrete events (such as disturbance due to fire, harvest, pest and disease outbreaks, land-use change, management practice change,

[20] Where no uncertainty ranges are provided by IPCC national inventory guidance, companies may apply an uncertainty range of ±90% the estimate provided.

etc.). Continuous processes generally affect biomass carbon stocks over large areas whereas discrete events impact specific areas.

Companies are required to account for and report on biomass carbon stock changes and the associated emissions and removals for land uses where management practices may significantly impact biomass. For Scope 1 and Scope 3 accounting, companies with the following lands that they own or control or are in their value chain, must account for and report biomass carbon stock changes:

- Forest lands
- Grasslands with woody or permanent cover
- Croplands with woody crops or crops with permanent cover
- Wetlands with woody or permanent cover
- Settlements with woody or permanent cover

If companies do not seek to account for and report *Land management net CO_2 removals* from biomass carbon stock changes, then accounting may follow the Tier 1 or Tier 2 guidelines below for either 1) assuming no biomass carbon stock change, or 2) calculating biomass net carbon stock changes using activity-based methods (i.e., Gain-Loss method with IPCC defaults).

When companies seek to account for and report *Land management net CO_2 removals* associated with net increases in biomass carbon stocks, accounting should follow the Tier 3 measurement and modeling guidance below as well as meet the CO_2 removals criteria for land management described in chapter 8.

Assume no biomass carbon stock change

Where land management practices have minimal impacts on biomass carbon stocks or their annual changes companies may apply an assumption of no biomass carbon stock changes. Companies may assume no biomass carbon stock change under the following land uses and conditions:

- Croplands with temporary non-woody cover (e.g., annual row crops) where there is no conversion between land uses, where the land has been under cultivation for at least 20 years, and where no management practice changes have occurred during the reporting period
- Grasslands with temporary non-woody cover (e.g., pastures without trees) where there is no conversion between land uses, where the land has been grazed for at least 20 years, and where no management practice changes have occurred during the reporting period
- Settlements where there is no conversion of land from other uses or between land uses, and where no management practice changes to land containing woody biomass have occurred during the reporting period
- Other lands where there is no conversion of land from other uses

Companies assuming no change in biomass carbon stocks in their accounting must monitor land management activities with the potential to impact biomass carbon. Such activities include:

- Croplands experiencing a permanent land management change including a change in crop rotation, irrigation or nutrient management that persists at least 3 years
- Croplands with management that may significantly impact biomass carbon stocks, including woody biomass removals, site preparation and prescribed fires
- Pastureland or grazing land where a significant modification of grazing intensity occurs and persists at least 3 years
- Grasslands with management that may significantly impact biomass carbon stocks, including woody biomass removals, site preparation and prescribed fires
- Settlements with management that may significantly impact biomass carbon stocks, including changes in land uses within settlements, tree planning and pruning and changes in landscape management

- Other land with management that may significantly impact biomass carbon stocks, including changes in land uses within other lands

Companies must estimate the biomass carbon lost as a result of these management changes if they occur on lands owned or controlled by the reporting company in Scope 1 reporting or land in the value chain of the reporting company in Scope 3 reporting. These carbon stock changes can be estimated using IPCC Tier 1 activity-based methods using international carbon stock change factors.

Activity-based approaches to estimate biomass carbon stock changes

Companies may apply activity-based methods to estimate biomass carbon stock changes resulting from land management practices using either the Gain-Loss or Stock-Difference method (see equation 8.1 and 8.2 in chapter 8 section 8.1.2). The Gain-Loss method estimates net biomass carbon stock changes based on the difference between the annual increase of biomass carbon stock due to growth with the annual decrease of carbon stock due to the biomass loss (due to harvests or other disturbances). Activity data on the total land area stratified by land use, climate, ecological zone and management are needed to estimate biomass growth using IPCC Tier 1 or country specific growth factors. Activity data on the volume of timber harvests and fuelwood removals, as well as area experiencing disturbance events are needed to estimate biomass losses using IPCC Tier 1 or country specific growth factors.

The Stock-Difference method estimates annual net biomass carbon stock changes based on the difference of carbon stock estimates at two different points in time divided by the time interval. Activity-based data on land use stratified by forest types is typically insufficient to estimate carbon stock changes using the Stock-Difference method based on Tier 1 data alone. Estimates of net land carbon stock should be based on repeated inventory plot measurements or other sampling protocol with a sufficient number of plots or samples to achieve a given level of precision at a given confidence level (e.g., within 20% of the mean at a 95% confidence interval) as described in the measurement-based approaches section below. Where Tier 2 national carbon stock estimates are available from national forest inventories, such data may be applied to estimate biomass carbon stock changes for relevant forest products within scope 3, recognizing the guidance on national boundaries. To apply the Stock-Difference method to estimate biomass carbon stock changes at the sourcing region or land management unit level Tier 3 remote sensing-based, model-based, measurement-based or hybrid approaches are recommended.

Remote sensing-based approaches to estimate biomass carbon stock changes

Remote sensing technology (satellite and aerial data) can effectively cover much larger areas in comparison to field measurement-based methods. Different types of remote sensing data are available to determine aboveground biomass, namely multispectral, hyper-spectral, as well as from active sensors such as light detection and ranging (LiDAR) and radio detection and ranging (radar) data. Local calibration and/or model development is required to derive aboveground biomass from the remotely sensed data. However, continued research may enable direct biomass measurements from satellite data, box 18.2 contains additional details on remote sensing technologies.

Box 18.2 Remote sensing technologies for detecting biomass carbon stock changes

Biomass remote sensing can be broadly classified using optical remote sensing, using natural radiation, or active remote sensing, using LiDAR or radar, as described below:

Optical remote sensing: This technology makes use of natural radiation from the sun to provide a two-dimensional view of vegetation and other surface features. This technology is easily accessible and affordable. The main limitation with this technology is rapid saturation with forest biomass as the reflectance signal in visible and near infrared is mostly correlated with the green leaf area index (LAI) and canopy cover of the vegetation, which saturates around a LAI of 3 to 4 m^2 m^{-2}. In addition, wood biomass becomes decoupled from LAI after a given stand age as wood biomass continues to increase after canopy closure. Thus, a direct relationship between spectral reflectance and forest biomass can only be observed where LAI is low. In natural forests the complexity is increased due to species and age mixtures resulting in complex forest stand structures. Optical remote sensing data must be combined with other data such as bioclimatic data, stand age, or forest inventory data to improve the biomass predictive capacity. Variable atmospheric conditions in time and space as well as topographic factors (slope and aspect) can affect vegetation reflectance and the resulting relationships between reflectance and aboveground biomass. Therefore, optical remote sensing data should be combined with other data such as LiDAR, bioclimatic data, stand age, or forest inventory data to improve the biomass predictive capacity.

Active remote sensing: LiDAR and radar technologies are the most promising techniques for forest biomass estimation as it penetrates through vegetation and thus provides additional information related to vegetation height and structure. Radar backscatter in the P and L bands is highly correlated with major forest parameters such as tree age, tree height, DBH, basal area and AGB. The saturation problem is also common in radar data and depend on the wavelengths, polarization and the characteristics of the vegetation stand structure and ground conditions. One benefit of LiDAR and radar data is that is less affected by cloud conditions (e.g., in tropical regions). Data can be acquired during the day and night as it is independent of light intensity. LiDAR data can be acquired during the day and night as it is independent of light intensity. Airborne LiDAR data is generally more expensive to collect and requires a high level of skill and knowledge to pre-process, remove noise and process the information into a final product. Although of courser spatial resolution than airborne data, satellite-based LiDAR data and related biomass products, such as those produced from GEDI, might provide a more cost-effective option for aboveground biomass quantification and validation.[21]

Model-based approaches to estimate biomass carbon stock changes

Modeling of biomass carbon stock changes can help improve annual estimates where biomass inventories are conducted at monitoring frequencies greater than one year. Applicable models can vary in scale depending on the spatial boundary of the analysis from local forest growth and yield models used to project stand-level dynamics to global vegetation models that can be used to develop national or regional estimates for biomass carbon stock changes. When selecting models, companies should consider a range of factors including the relevance of the model to the specific land use, geography or management practices, data availability both for input variables and calibrating the model, uncertainty analysis capabilities, technical capacity of the inventory team to run the model and quality assurance and quality control procedures needed to document and report model result. Calibration of biomass models should be based on data collection through ground-based inventories or other direct sampling approaches as described in the measurement-based approaches below. Measurements should be used to verify model results every 5 years as described in chapter 8.

Measurement-based approaches to estimate biomass carbon stocks and carbon stock changes

Biomass carbon stock changes should be measured through resampling of field plots for a particular stratum or comprehensive inventory methods. When applied in an inventory context, measurements should begin in the base year or base period and apply consistent methods when resampling over time.

[21] Duncanson et al., 2022

Biomass carbon stocks can be measured through use of either ground-based measurements of tree diameter and height or destructive biomass sampling techniques. Companies should report internationally recognized peer-reviewed publication or protocols of allometric equations, inventory methods or destructive biomass sampling protocols applied to measure biomass carbon stock on relevant lands or strata.[22] Inventory methods or other sampling protocols should specify which components of aboveground biomass (e.g., aboveground live tree biomass, herbaceous biomass) and belowground biomass (e.g., coarse root biomass, fine root biomass) are included in the biomass carbon stock estimates. Companies should justify any exclusions when estimating biomass carbon stocks using measurement-based approaches.

Aboveground live tree biomass (woody-stem diameter size classes ≥1 cm, unless otherwise specified)

Aboveground live tree biomass is typically estimated using field measurements of tree diameter and height with relevant allometric equations. Allometric equations are empirical models used to estimate properties such as total biomass from non-destructive measurements of tree characteristics. Such models are developed through destructive sampling of biomass in the tree or shrub trunk, branches, twigs and foliage across a representative sample size of individual trees or shrubs.[23] The most commonly used independent variable in allometric equations is diameter at breast height (which, for most countries, is measured at 1.3 m from soil surface). Allometric equations may also require additional field measurements such as tree canopy height and wood density or provide alternative guidance on measuring trunk diameter based on the vegetation type.

Herbaceous biomass (non-woody vegetation or woody-stem diameter size classes <1 cm, unless otherwise specified)

Herbaceous biomass includes non-woody vegetation such as crops, grasses, sedges, forbs or vines as well as plants with woody stems <1 cm in diameter. Herbaceous biomass can significantly contribute to the carbon stocks of grasslands and croplands as well as certain forest types. Herbaceous biomass carbon stocks can be sampled through destructive sampling within representative plots or subplots. Plots are typically sampled within 2 weeks of peak biomass for the vegetation type where all herbaceous biomass is clipped within the plot or along a strip depending on the protocol. Herbaceous biomass is then dried to determine the total dry weight of aboveground biomass recovered as well as measurement of carbon content of biomass using elemental analyzers.

Belowground biomass (root diameter size classes ≥2 cm, unless otherwise specified)

Estimates for biomass carbon stocks for belowground biomass are often determined based on the aboveground biomass estimates for a given vegetation type. Allometric equations used to estimate belowground biomass based on aboveground biomass, commonly referred to as root-to-shoot ratios, can be developed based on destructive sampling techniques. Destructive sampling of root biomass is labor intensive requiring sampling belowground biomass by taking multiple soil cores within plots or subplots to a minimum depth of 20cm to 1m depending on the ecosystem and vegetation type. Soil samples are then commonly sieved to separate coarse roots (typically defined as >1cm) as well as fine root fragments <1cm but >2mm. Root biomass is then dried to determine the total dry weight of root biomass recovered as well as measurement of carbon content of root biomass using elemental analyzers.[24]

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[22] https://www.neonscience.org/data-collection/terrestrial-plants

[23] Roxburgh et al., 2015

[24] Mokany, Raison & Prokushkin, 2006

18.2.2 Dead organic matter (DOM) carbon stock changes

Dead organic matter consists of dead wood and litter carbon pools. The dead wood pool includes standing dead trees, downed woody debris, forestry residues, dead coarse roots, and other dead material larger or equal to 10 cm in diameter or otherwise specified. Litter includes all non-living biomass less than the diameter threshold for dead wood but greater than the 2mm threshold for soil organic matter, including forest litter and agricultural residues. Dead organic matter carbon stocks can be influenced by both management decisions such as forestry or agricultural residue management practices, fuel treatments for wildfire management or natural factors such as natural disturbances generating converting biomass to dead organic matter or changes to temperature and precipitation impacting decay rates.

Companies are required to account for and report on DOM carbon stock changes and the associated emissions and removals for land uses only where management practices may significantly impact DOM. For Scope 1 and Scope 3 accounting, companies with the following lands that they own or control or are in their value chain, must account for and report DOM carbon stock changes:

- Forest lands where management practices significantly impact forestry residues or deadwood
- Grasslands where management practices significantly impact residues or deadwood
- Croplands where management practices significantly impact agricultural residues

Assume no change in DOM carbon stocks

Where land management practices have minimal impacts on dead organic matter carbon stocks, or their annual changes, companies may apply an assumption that of the net carbon stock changes of DOM are zero or there are no dead organic matter carbon stock changes. Companies may assume no dead organic matter carbon stock change under the following land uses and conditions:

- Forest lands where there is no conversion between land uses, and where no management practice changes have occurred during the reporting period
- Grasslands where there is no conversion between land uses, where the land has been grazed for at least 20 years, and where no residue management practice changes have occurred during the reporting period
- Croplands where there is no conversion between land uses, where the land has been under cultivation for at least 20 years, and where no residue management practice changes have occurred during the reporting period
- Settlements where there is no conversion between land uses, and where no management practice changes to land containing dead organic matter have occurred during the reporting period
- Other lands where there is no conversion of land from other uses

Companies assuming no change in dead organic matter carbon stocks in their accounting must monitor land management activities with the potential to impact dead organic matter carbon. Such activities include:

- Forest lands with management that may significantly impact dead organic matter carbon stocks, including changes in forest residue management, fuel wood removals, site preparation, and prescribed fires
- Grasslands with management that may significantly impact dead organic matter carbon stocks, including fuel wood removals, site preparation and prescribed fires
- Croplands with management that may significantly impact dead organic matter carbon stocks, including changes in crop residue management, fuel wood removals, site preparation and prescribed fires
- Settlements with management that may significantly impact dead organic matter carbon stocks, including changes in land uses within settlements and changes in landscape management

- Other land with management that may significantly impact dead organic matter carbon stocks, including changes in land uses within other lands

Companies would be required to provide estimates of the dead organic matter carbon stock changes as a result of these management changes if they occur on lands owned or controlled by the reporting company in Scope 1 reporting or land in the value chain of the reporting company in Scope 3 reporting. These estimates can be provided using IPCC Tier 1 activity-based methods using international carbon stock change factors.

Activity-based methods to estimate DOM carbon stock changes

Companies can apply activity-based methods to estimate carbon stock changes of DOM pool resulting from land management practices using either the Gain-Loss or Stock-Difference method (see equation 8.1 and 8.2 in chapter 8 section 8.1.2).

The Gain-Loss method estimates carbon stock changes based on the mass balance of input to and losses, from the dead wood and litter carbon pools. This approach requires the data of annual transfer into the DOM from stem mortality, litterfall and turnover and the output from DOM such as decomposition rates.

Estimating the carbon stock changes of DOM using the Stock-Difference approach requires estimates of the dead wood and litter carbon stock at two different times. The annual carbon stock change is calculated as the difference of two estimates of dead wood and litter carbon stock divided by the time period between two measurements.

To calculate the change in carbon stocks from DOM using those methods requires the area of managed lands (activity data) which is multiplied by a DOM carbon stock change factor obtained either using Gain-Loss or Stock-Difference approach. Since the Tier 1 IPCC assumes no net changes in carbon stocks of DOM and Tier 2 using the national data, the activity-based approaches do not meet the criteria for accounting for and reporting CO_2 removals in corporate GHG inventories.

Tier 3 methods are data intensive and require field measurement and modeling to estimate the carbon stock changes from DOM as explained in the following sections.

Remote sensing-based approaches to estimate DOM carbon stock changes

The application remote sensing technology for estimating DOM carbon stock changes is still quite limited and research is still in development to use optical remote sensing from either satellites or aerial imagery to identify and map coarse and large woody debris. This technique uses the pixel-based approach such as linear regression, classification trees, and machine learning to get the characteristic of coarse woody debris. The success level of optical remote sensing in identifying coarse woody debris is limited by tree canopy cover and understory coverage since those features conceal the extent of the coarse woody debris on the forest floor. Use of aerial imagery in riparian areas with low vegetation coverage in post-disturbance situations (e.g., fires, hurricanes) shows promising results in detecting coarse woody debris. However, it has limited capabilities in identifying and mapping coarse woody debris in forested areas with high vegetation cover.

As an alternative to optical remote sensing, LiDAR is capable of providing information from the forest floor and understory under the vegetation canopy. This technology is valuable for coarse woody debris assessment, especially in areas with high vegetation coverage. The combination of aerial imagery, LiDAR and multispectral LiDAR may provide increased accuracy and spatial coverage. Early results indicate high resolution coarse woody debris volume maps from both visible and occluded coarse woody debris in the boreal forest show good agreement with field inventory data.

Measurement-based approaches to estimate DOM carbon stocks and carbon stock changes

Repeated field measurements of DOM carbon stock changes over time are both labor intensive and time consuming, especially for covering large areas or numerous strata. The follow methods can be used to estimate the various component of DOM carbon stocks for a single point in time, including standing dead trees, dead woody debris and litter.

Standing dead tree biomass

In the field, the standing dead trees can be classified into three status classes that will be used in the calculation of dead trees biomass:

- Status 1: Small branches and twigs are retained; resembles a live tree except for absence of leaves
- Status 2: No twigs/small branches; may have lost a portion of large branches
- Status 3: Few or no branches, has standing trunk or main stem only; the main stem may be broken

Volume and associated carbon stock values associated with standing dead trees can be estimated using similar methods to standing live biomass described above. Where biomass expansion factors or allometric equations are applied they should be specific to tree species and disturbance type where possible and appropriately factor in biomass reductions and the decay class of the standing dead trees.

Downed woody debris (diameter size classes ≥10 cm, unless otherwise specified)

There are two main methodologies to estimate the downed woody debris from a field measurement: plot-based and line-intersect method:

- **Plot-based method**: the downed woody volume is calculated by measuring both diameter at both ends and the length of woody debris.
- **Planar intersect method**: counts woody debris intersected along several installed transect within a plot. The woody debris crossing the transect are separated into different diameter classes. The length of a transect can vary from 10-20 m depending on the woody debris abundance.

Litter (diameter size classes ≥2 mm and <10 cm, unless otherwise specified)

Litter is defined as the surface detritus and particulate organic matter that lies above the soil surface, excluding larger fragments of wood that is measured under the downed woody debris pool. Forest floor litter consists of fallen leaves, seeds, fruit, bark fragments and small pieces of wood. In the field, litter biomass is calculated by harvesting and weighing all material located inside the microplots with the dimension ranges from 25 x 25 cm to 50 x 50 cm.

18.2.3 Soil carbon stock changes

Land management can impact the carbon in the soil, where soil disturbance can result in losses of carbon through surface erosion or emissions from increased soil respiration, while regenerative practices can increase soil carbon content through increasing organic matter inputs or minimizing emissions from soil respiration. Cultivation of organic soils can also result in large emissions of carbon as these soils contain much larger soil carbon stocks than mineral soils (see chapter 4 for organic and mineral soil definitions). Because of the historical losses of soil carbon due to land use change and disturbance, restoration of soil carbon through land management has become a potential tool for mitigating climate change by removing atmospheric CO_2.

Soil carbon is made up of two components: soil organic carbon and soil inorganic carbon. Soil organic carbon (SOC) can be built up or lost through land management activities and natural factors such as changes in vegetative carbon inputs to soils, changes in land use, soil tillage practices, temperature and/or precipitation impacting soil organic matter decay rates, management factors influencing soil erosion, etc. SOC impacts biogenic net CO_2 emissions and removals as measured through net changes in soil carbon stocks. Soil inorganic carbon (SIC) cannot be built up over decadal timescales, but can be lost through land management and natural factors – principally by activities that acidify soil leading to the loss of $CaCO_3$ (e.g., acid rain or through use of ammonium-based fertilizers). Inventories may include soil inorganic carbon changes if sufficient information is available to use a Tier 3 methodology.

Companies are required to account for and report on soil carbon stock changes and the associated emissions and removals for land uses where management practices may significantly impact soils. For Scope 1 and Scope 3 accounting, companies with the following lands that they own or control or are in their value chain, must account for and report soil carbon stock changes:

- Grasslands with management practice changes
- Croplands with management practice changes
- Forest lands where management practices significantly disturb soils
- Wetlands where management practices significantly disturb soils
- Settlements where management practices significantly disturb soils

If companies do not seek to account for and report *Land management net CO_2 removals* from soil carbon stock changes, then accounting may follow the Tier 1 or Tier 2 guidelines below for either 1) assuming no soil carbon stock change, or 2) calculating soil net carbon stock changes using activity-based methods (i.e., using IPCC default emission factors, carbon stock change factors and reference soil carbon stocks by strata).

When companies seek to account for and report *Land management net CO_2 removals* associated with net increases in soil carbon stocks, accounting should follow the Tier 3 measurement and modeling guidance below as well as meet the CO_2 removals criteria for land management described in chapter 8.

Assume no soil carbon stock change

Where land management practices have minimal impacts on soil carbon stocks companies may apply an assumption of no soil carbon stock changes. If drained organic soils are included in the inventory being reported, emissions from those soils must be included, following guidance in the next section. Companies may assume no soil carbon stock change under the following land uses and conditions:

- Croplands on mineral soils where there is no conversion of land from other uses to agricultural production, where the land has been under cultivation for at least 20 years, and where no management practice changes have occurred during the reporting period
- Pasturelands or grasslands on mineral soils where there is no conversion of land from other uses to agricultural production, where the land has been grazed for at least 20 years, and where no changes have occurred to grazing intensity and practices during the reporting period
- Forest land on mineral soils where there is no conversion of land from other uses to silvicultural production, and where no significant disturbance to soils through forest management have occurred during the reporting period
- Settlements on mineral soils where there is no conversion of land from other uses, and where no soil excavation or trenching have occurred during the reporting period
- Other lands on mineral soils where there is no conversion of land from other uses

Companies assuming no change in soil carbon stocks in their accounting must monitor land management activities with the potential to impact soil carbon. Such activities include:

- Croplands experiencing a permanent land management change including a change in crop rotation, tillage intensity, residue treatment, irrigation or nutrient management that persists at least 3 years
  Cropland undergoing any physical modification of a field (e.g., leveling, tile drain installation)

- Pastureland or grazing land where a significant modification of grazing intensity and practices occurs and persists at least 3 years. Grazing land undergoing any physical modification of a field
- Ungrazed grasslands with management that may significantly impact soil carbon stocks, including road construction, site preparation and prescribed fires
- Forest lands with management that may significantly impact soil carbon stocks, including forest road construction, site preparation, harvest practices (e.g., skid trails) and prescribed fires
- Settlements with management that may significantly impact soil carbon stocks, including excavation, trenching, changes in land uses within settlements, and changes in landscape management
- Other land with management that may significantly impact soil carbon stocks, including changes in land uses within other lands

Companies should provide estimates of the soil carbon stock changes as a result of these management changes if they occur on lands owned or controlled by the reporting company in scope 1 or land in the value chain of the reporting company in scope 3. These estimates can be provided using IPCC Tier 1 activity-based methods using international carbon stock change factors.

Activity-based approaches to estimate soil carbon stock changes

Companies can apply activity-based methods to estimate potential soil carbon stock changes resulting from land management changes when desired or when significant land management change has occurred and the assumption of no change in stock is not valid but no carbon removal is being claimed. These activity-based methods, however, must be paired with empirical measurements to spot check any removal claims (see below). Activity-based methods can also be used to estimate carbon emissions from land management on drained organic soils, using IPCC emission factors.[25] Use of such activity-based methods has the advantage of being relatively simple to implement. Particularly in a Scope 3 context, carbon stock change factors can be applied based on knowledge of the land area adopting a given practice change on agricultural land. Both Tier 1 and Tier 2 methods can be used for this calculation:

- **Tier 1** carbon stock change factor approaches assign a standard soil carbon gain or loss factor for certain specific agricultural management practice changes and can be used to generate aggregate soil carbon change estimates. Factors can be generated through literature review and meta-analysis of observations from research plots or from meta-modeling approaches that use detailed research models to simulate potential soil carbon change based on a range of management assumptions for a given region.
- **Tier 2** carbon stock change factors relevant to national or subnational levels must account for specific regional conditions such as weather and climate variation and soil properties in addition to management practice changes.

Tier 1 methods should only be used when the sourcing region is defined at the national level or broader, or no other data is available. Where national or management specific data are available, Tier 2 should be used. For both Tier 1 and Tier 2 approaches, emission factors should be developed based on peer-reviewed literature relevant to the region, soil types and production systems being assessed. For some regions and countries, national databases and guidance on soil carbon may be available. For some countries, the National Inventory Report that is submitted to UNFCCC yearly (section 6.3 of the NIR)[26] may contain such information. Many countries are developing research programs and adopting their results as official references for soil stock and

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[25] IPCC, 2013

[26] Available at https://unfccc.int/ghg-inventories-annex-i-parties/2020

soil stock changes in time. Mathematical models based on extensive sampling are also made available for use. These values are peer-reviewed and externally verified by UNFCCC through their Expert Review Team (ERT) annually. Other examples of available tools that incorporate literature derived carbon stock change factors to estimate soil carbon stock changes can be found under GHG Protocol [Calculation Guidance or sector specific tools]. Alternatively, carbon stock change factors can be developed using extensive application of process-based soil carbon models (see below). Model-based or measurement-based approaches used to develop Tier 3 carbon stock change factors should conform to the guidance provided below.

Model-based approaches to estimate soil carbon stock changes

For reporting CO_2 removals from increases in soil carbon stocks, measurements in the base year and at 5 year intervals can be complemented by use of simulation modeling that meets IPCC Tier 3 guidelines. Process-based biophysical models of agro-ecosystems can be used to simulate changes in soil carbon stocks resulting from land management changes. These models account for specific field and location conditions such as soil properties, topography, weather, and comprehensive management decisions including crop rotation, tillage intensity, irrigation, nutrient management, residue management and other in-field practices. The advantage of models is that they represent biogeochemical processes and therefore could be expected to be more transferrable and accurate across gradients in environmental factors than IPCC emissions factors.

Several biogeochemical models that meet IPCC Tier 3 guidelines for CO_2 emissions and removals and can be used for estimating annual changes in soil carbon stocks.

Process-based models are complex and require extensive background data on environmental conditions and accurate parameterization for a given region and set of circumstances. Further, modelling requires periodic calibration against measured values and updating of supporting environmental data. Decision support tools developed from these complex models can provide a user-friendly interface and standard, tested parameterizations and are suitable for use by non-experts.

Remote sensing-based approaches to estimate soil carbon stock changes

Soil carbon cannot be detected directly through satellite remote sensing; however, such approaches can be used to detect changes in land cover and land management. Land cover and management data derived from remote sensing products can then be used to estimate changes in soil carbon stocks using emission factors, statistical models, or process-based models. While land cover change remote sensing methods are relatively advanced and accessible, land management change remote sensing is primarily focused on detecting changes in crop rotation, including cover crop use, and changes in tillage intensity on agricultural lands. As such, it may not apply to all relevant agricultural practices. Remote sensing derived maps of conservation practice adoption may also be useful for verification of reported practice changes by farmers in a region.

Measurement-based approaches to estimate soil carbon stocks and soil carbon stock changes

A sampling protocol can be used to measure soil carbon stock change on a select portion of the land area contributing to the soil carbon stock changes. Companies should follow an established sampling protocol that accounts for variation of important environmental factors and stratifies that total land area included in the analysis to ensure that measurements are taken in locations that are representative of the given spatial boundaries (see chapter 8 for guidance on determining the spatial boundary). Soil properties and management practice changes on the sampled lands must be representative of the full land area contributing to the soil carbon stock changes. The same plots should be measured in the base year or period and the subsequent measurement years.

Table 18.2 describes the three factors that are essential to measuring soil carbon stocks and soil carbon stock changes over time:

Table 18.2 Description of key elements of soil carbon stock measurements

Key elements of soil carbon stock measurements	Description
1. Sample design and stratification	The first step in measurement-based approaches is to determine where to collect samples. The statistical approaches to sampling design should be consistent with land management plans to inform other soil sampling objectives including nutrient management, soil pH, soil health or other sampling requirements specified by related GHG programs. In brief, methods like k-means clustering combined with point randomization or conditional Latin Hyper Cube sampling can be used to generate a set of sampling points based on factors that are known to affect soil carbon, like soil mineralogy, soil texture, vegetation, and climate. It is important to follow a field sampling protocol for measuring soil carbon stocks. A standard operating procedure for collecting samples for soil carbon stock quantification can be found from the Soil Health Institute's Soil Health Sampling Protocol (SHI SHS Protocol) and Food and Agriculture Organization's Global Symposium on Soil Organic Carbon Monitoring Reporting and Verification Protocol (FAO GSOC-MRV Protocol).[27]
2. Bulk density and equivalent soil mass accounting methods	Bulk density, the mass of soil per volume, is necessary to calculate the soil carbon stock for a given land area or stratum. Analytical measurements provide the concentration of carbon in a sample. Multiplying concentration by bulk density gives a stock in units such as kg C per ha to a depth reflective of the impacts of soil tillage (which can vary from 30 to 100 cm depth depending on tillage practices representative of the total land area included). However, management practices can impact bulk density as well as soil carbon. This means that changes in carbon stocks can be observed just through changes in bulk density to a fixed soil depth. This can improperly suggest progress toward climate mitigation when no true change in carbon sequestration has occurred. To address this, measurement-based reports on carbon removals should use equivalent soil mass accounting methods.[28] However, because most activity-based and model-based approaches represent soil carbon as mass per volume, it will be necessary to also work-up stock estimates both ways so that they can be used to validate and parameterize models. It should be noted that the field data collected for equivalent soil mass accountings vs. bulk density are the same.

[27] Available at SHI SHS Protocol (https://soilhealthinstitute.org/app/uploads/2022/06/SOP_SoilSampling-v3.pdf) and FAO GSOC-MRV Protocol (http://www.fao.org/documents/card/en/c/cb0509en)

[28] Wendt and Hauser, 2013

3. Soil carbon measurement	There are several methods to measure soil carbon, including elemental analysis (sometimes referred to as dry combustion), loss on ignition and spectroscopic methods. Direct sampling of carbon stock changes to estimate CO_2 removals should be based on measuring carbon through combustion in an elemental analyzer.[29] In this method, a soil sample is thoroughly combusted and the conversion of carbon to CO_2 is measured. Loss on ignition, which measures the mass loss after thermal combustion of a soil sample, should *not* be used given concerns about its precision. More recently, methods such as non-destructive soil spectroscopy have been developed. These newer methods can be advantageous because of lower per sample costs, however algorithms essential to their implementation require extensive calibration and concerns remain about the comparability of results generated using different spectroscopy instruments. Currently there are no consensus methods or training datasets that would ensure comparability of results across laboratories/projects. If soil spectroscopy is used as a measurement approach, samples should be thoroughly dried and ground and analyzed at a single lab. Mid-infrared instrumentation (as opposed to visual and near infrared methods) should be used and methods and training datasets used to generate estimation algorithms must be thoroughly documented, including sharing of statistical source code and raw data. Further, at least 20% of the samples, randomly chosen, should also be measured using elemental analysis to calibrate any soil spectroscopy protocols. Accuracy of the estimation algorithm should be reported as the root mean square error of carbon content estimated via spectroscopy versus the true carbon content of test samples as measured via elemental analysis. In general, because of among-lab error, soil properties should be measured at a single lab, both within a sampling effort and across sampling efforts (ie. at different years).

18.3 Flow accounting methods

Section 18.3 provides guidance on flow-based accounting methods companies can use to account for the individual gross biogenic CO_2 emissions and removals from land management including *Gross biogenic land CO_2 removals* (section 18.3.1), *Gross biogenic land CO_2 emissions* (section 18.3.2), and gross biogenic carbon stock losses from harvest (section 18.3.3).

18.3.1 Gross biogenic land CO_2 removals

Under flow-based carbon accounting, biogenic CO_2 removals are estimated based on the gross carbon flows from the atmosphere to storage within biomass carbon pools. Gross biogenic land management CO_2 removals are largely the result of photosynthesis where atmospheric CO_2 is converted to organic carbon in plant biomass through plant growth. For example, any growth in trees or herbaceous understory growth on forest lands or annual crop grow on croplands would be included in estimates for *Gross biogenic land CO_2 removals*.

Direct (or scope 1) *Gross biogenic land CO_2 removals* occur on lands owned/controlled by the reporting companies that are included in their organizational boundary. Indirect (or scope 3) *Gross biogenic land CO_2*

[29] FAO GSOC-MRV Protocol, 2020 (http://www.fao.org/documents/card/en/c/cb0509en)

removals occur as a consequence of activities of the reporting company but on lands owned/controlled by another entity in the value chain of the reporting company. Flow-based accounting requires full life cycle accounting for any corresponding *Gross biogenic land CO_2 emissions* from the land or transfers of carbon to products or geologic carbon pools to ensure permanence of *Gross biogenic land CO_2 removals*.

Gross biogenic land CO_2 removals estimates are often based on proxy measurements of gross land carbon stock increases associated with biomass growth as opposed to direct measurement of CO_2 uptake or gross primary productivity. IPCC guidelines for national GHG inventories provides global Tier 1 estimates of average annual aboveground biomass growth for specific vegetation types by land use. They also provide root-to-shoot ratios (i.e., the ratio of belowground biomass to aboveground biomass for a specific vegetation type) to estimate corresponding belowground biomass growth. Companies may obtain Tier 2 data on growth rates from published literature or used in relevant national GHG inventories to estimate *Gross biogenic land CO_2 removals*. Where Tier 3 methods are applied companies may sample growth rates from repeated measurement in sample plots in accordance with measurement-based approaches or model growth based on calibrated model-based approaches as described in section 18.1.2.

18.3.2 Gross biogenic land CO_2 emissions

Under flow-based carbon accounting, *Gross biogenic land CO_2 emissions* are estimated based on the gross carbon flows from land-based carbon pools directly to the atmosphere. Gross biogenic land CO_2 emissions can result from disturbance events such as fires or disease, or due to decomposition of dead organic matter or soil organic matter through ecosystem respiration processes. *Gross biogenic land CO_2 emissions* are distinct from *Gross biogenic product CO_2 emissions*, which represent CO_2 emissions that occur at sources where biogenic products are combusted or decomposed. For example, if forest residues are piled and burned on the land such CO_2 emissions should be reported as *Gross biogenic land CO_2 emissions*, however if such residues were collected and sold as fuel wood the emissions resulting from combustion would be reported as *Gross biogenic product CO_2 emissions*.

Direct (or scope 1) *Gross biogenic land CO_2 emissions* occur from carbon pool on lands owned/controlled by the reporting companies that are included in their organizational boundary. Indirect (or scope 3) *Gross biogenic land CO_2 emissions* occur as a consequence of activities of the reporting company but on lands owned/controlled by another entity in the value chain of the reporting company.

Gross biogenic land CO_2 emissions estimates are often based on proxy measurements of gross land carbon stock decreases associated with fire, disturbances and soil respiration as opposed to direct measurement of CO_2 emissions from land-based carbon pools. For estimating gross biogenic land CO_2 emissions from fires, companies may apply equation 19.19 using IPCC emission factors for CO_2 (see chapter 19 section 19.4). For estimating gross biogenic land CO_2 emissions from disturbances other than fire, IPCC guidelines for national GHG inventories provides global Tier 1 emission factors to estimate annual carbon losses due to disturbance based on average biomass for specific vegetation types by land use. Companies may assume all biomass is lost in the year the disturbance occurs unless they know the fraction of biomass lost in the disturbance. Companies may apply IPCC Tier 1 soil carbon stock change factors to estimate gross soil carbon stock losses associated with gross biogenic land CO_2 emissions from soil respiration. Companies may obtain Tier 2 data on gross land carbon stock losses from published literature or may use data from relevant national GHG inventories to estimate *Gross biogenic land CO_2 emissions*. Where Tier 3 methods are applied companies may sample gross land carbon stock losses due to fire, disturbances or soil respiration from repeated measurement in sample plots in accordance with measurement-based approaches or model land-based CO_2 emissions based on calibrated model-based approaches as described in section 18.1.2.

18.3.3 Gross land carbon transfers

In addition to tracking gross biogenic CO_2 emissions and removals on the land, companies are encouraged to also account for gross land carbon transfers such as carbon losses from harvest or collection or agricultural or forest residues. Gross biogenic carbon transfers relevant to land carbon pools include any exchange of carbon from land-based carbon pools to product carbon pools. They are largely associated with harvests or the carbon losses from biomass carbon pools added to biogenic product carbon pools. For example, wood removals of timber taken off forest lands or harvest of soybeans from a soy plantations would both represent a gross biogenic carbon transfer. Gross land carbon transfers can also include exchanges of carbon from product carbon pools to land-based carbon pools, such as biochar application to soils.

Under stock-change accounting such transfers contribute to the net land carbon stock change used to estimate the net biogenic CO_2 flux on the land. Under flow-based accounting, such transfers do not contribute to *Gross biogenic land CO_2 emissions* but instead are accounted for as *Gross biogenic product CO_2 emissions* depending on their fate in the processing, use or end-of-life phase (see chapter 20 for details).

Gross land carbon transfers are estimated based on the mass or volume of the harvested materials. Where companies quantify harvests based on volumes, total carbon can be calculated by multiplying the harvested volume by the density and carbon fraction of dry matter for the material. Where companies quantify harvests based on mass, total carbon can be calculated by multiplying the harvested dry weight by the carbon fraction of dry matter for the material. The IPCC guidelines for national GHG inventories provides global Tier 1 estimates of average carbon fraction of dry matter and wood densities for specific vegetation types by land use. Companies can also conduct direct sampling of harvested materials for more accurate assessments of the density or carbon fraction of dry matter through lab analysis.

Land Management Non-CO_2 Emissions Calculation Guidance

Chapter 19: Land Management Non-CO_2 Emissions

Calculation Guidance

This chapter provides calculation guidance on quantifying greenhouse gas emissions relating to the production of land-based products from a scope 1 and scope 3 perspective. Land management non-CO_2 emissions include those from livestock, agricultural soils and inputs, biomass burning, rice productions and energy use occurring on lands. This excludes emissions from carbon stock changes due to land management, which is covered in chapter 18, and land use change emissions, which is covered in chapter 17.

This chapter draws directly from the Greenhouse Gas Protocol's Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories (GPC), Chapter 10: Agriculture, Forestry and Other Land Use, which summarizes calculation methods for agriculture, forestry and other land use contained in Volume IV of the IPCC Guidelines for National Greenhouse Gas Inventories.

Sections in this chapter

Section	Description
19.1	Introduction to calculating land management non-CO_2 emissions
19.2	Emissions from livestock
19.3	Emissions from managed soils
19.4	Emissions from biomass burning and fires
19.5	Emissions from rice cultivation and flooded lands
19.6	Other GHG emissions from land management

19.1 Introduction to calculating land management non-CO_2 emissions

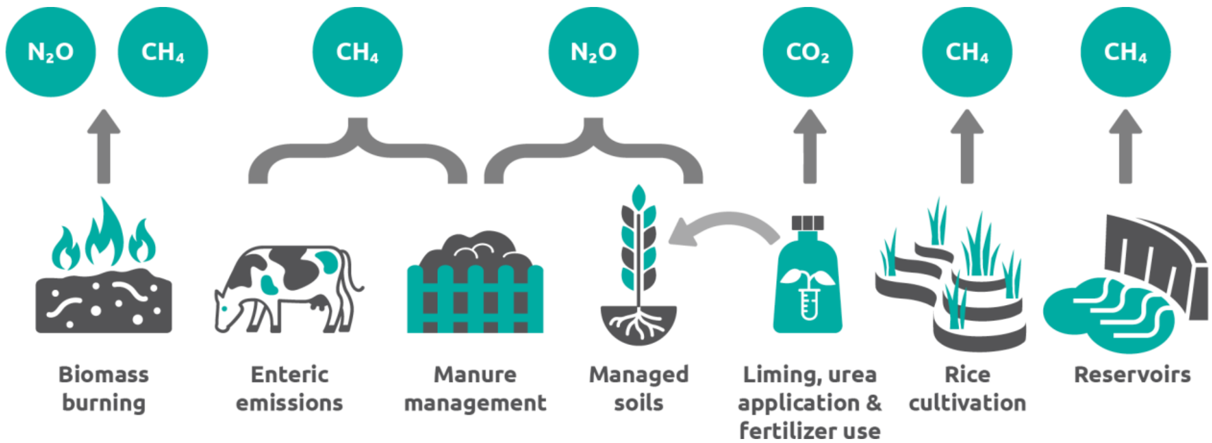
19.1.1 Land management source categories

Land management GHG emissions accounting helps companies measure the GHG emissions that occur on managed lands, whether that land produces food, feed, fiber or other biogenic product(s). This chapter provides guidance on the data, methods, and equations required to calculate emissions for the following land management source categories:

- CH_4 and N_2O emissions from livestock (section 19.2)
- Non-biogenic CO_2 and N_2O emissions from managed soils (section 19.3)
- CH_4 and N_2O emissions from biomass burning and fires (section 19.4)
- CH_4 emissions rice cultivation and flooded lands (section 19.5)
- Other CH_4, N_2O, and non-biogenic CO_2 emissions from land management (section 19.6)

Note that while non-biogenic CO_2 is listed in the source categories above and addressed in this chapter, biogenic CO_2 emissions are addressed in chapter 18.

Figure 19.1 Overview of land management GHG emissions source categories



19.1.2 Data for estimating land management GHG emissions

Each type of land management GHG emissions has several different calculation methods available and many different data inputs required to account for GHG emissions. Calculation options and data sources can be generalized using the “tier” system used in the IPCC *Guidelines for National GHG Inventories*:

- Tier 1 methods use global default emission factors and activity data on average land management practices.
- Tier 2 methods use country-level or geographically-specific emission factors and activity data on average land management practices specific to those regions.
- Tier 3 methods use directly monitored emissions, modeled emissions or site-specific (derived from actual measurements) emission factors and activity data specific to the adopted land management practice.

This chapter provides detailed quantification guidance on using Tier 2 and 3 methodologies, as well as options using the following global Tier 1 emission factors based on the reporting company’s data availability and supply chain traceability:

- Tier 1 emission factors tend to be conservative, leading to overestimation of emissions based on global uncertainty ranges.
- Tier 2 emission factors and activity data are more specific to regions of origin and can reduce uncertainty relative to Tier 1 estimates.
- Tier 3 methods and data are based on actual monitoring or modeling of emissions and activity data from the actual land management practices and provide the highest level of accuracy that can best capture land management emissions and associated improvements or mitigation activities on relevant lands.

The rest of the chapter describes Tier 1 and 2 emission factors and methods that can be used to estimate land management GHG emissions and give details on higher-order models that could be used in Tier 3 calculations. In general, companies are encouraged to use or develop Tier 2 or Tier 3 models specific to their owned or managed land or where they have traceability to the land management units of origin. However, Tier 1 and 2 emission factors and databases for biogenic materials or products are available for estimating land management emissions in scope 3 when companies have limited traceability. Further details on collecting data, determining data quality and improving traceability can be found in chapter 16.

Within global Tier 1 accounting methods, life-cycle emission factors from databases will likely be aggregated across several categories of emissions. It is therefore important to understand which categories are included in the factor being used to ensure complete accounting of land management GHG emissions.

19.1.3 Connections between land management GHG emissions and carbon stock change accounting

GHG emissions from certain land management source categories are closely linked to factors impacting land carbon stock changes. Companies should use similar methods, data and assumptions where estimating GHG emissions (as described in this chapter) and carbon stock changes (as described in chapter 18) for similar land management activities. The following sections detail specific considerations for accounting for GHG emissions and carbon stock changes from fires and managed soils.

GHG emissions and carbon stock changes from managed soil

Management of soils across land uses can impact the climate through both changes in soil carbon stocks as well as methane (CH_4) and nitrous oxide (N_2O) emissions due to soil organic matter cycling. Soil carbon and nitrogen cycling are closely linked and affected by similar factors including the rate and type of soil organic matter inputs (e.g., crop residues, organic fertilizers, manure or other soil organic amendments), temperature, water management, soil tillage practices and other factors. The following calculations should apply similar data and assumptions:

- For livestock systems, similar data and assumptions regarding livestock populations, N excretion rates, manure harvesting and manure application on managed soils should be used when accounting for N_2O emissions from organic N inputs to soils, N deposited as urine or dung on pasture range and paddock, and soil carbon stock changes from manure C inputs. (see chapter 18)
- For managed cropland and forestlands, similar data and assumptions regarding crop or forestry residue management should be used when accounting for N_2O emissions from residue N inputs to soils, soil carbon stock changes from residue C inputs to soils (see chapter 18), and GHG emissions from residue burning.
- In flooded rice systems, similar data and assumptions regarding the water management regime, fertilizer use, organic amendments and soil type should be used to estimate CH_4 emissions from rice cultivation, N_2O emissions from N inputs to soils and soil carbon stock changes (see chapter 18).

Where companies apply Tier 3 model-based approaches to estimate soil carbon stock changes, the same biogeochemical model should be applied to estimate N cycling and associated N_2O emissions from managed soils and CH_4 emissions from rice cultivation.

GHG emissions and carbon stock changes from fire

Fires result in both non-CO_2 GHG emissions and losses of carbon from biomass, dead organic matter (e.g., deadwood and agricultural or forestry residues) and soil carbon pools. When accounting for GHG emissions from fire, the gross biogenic CO_2 emissions are also accounted for in estimates of net carbon stock changes on the land based on the carbon stock losses due to fires.

Companies should account for and report both the net carbon stock changes and gross biogenic CO_2 emissions from fires in accordance with the guidance in chapter 18. Companies should use similar data and assumptions to account for the CH_4 and N_2O emissions from fires following the methods described in section 19.4 and report these emissions in the relevant scope.

19.1.4 Reporting direct and indirect N_2O emissions

Nitrogen management from agricultural crops and livestock systems contributes 52% of global anthropogenic N_2O emission.[30] N_2O emissions can occur directly from management systems or indirectly from transformation of other nitrogen losses from management systems. Direct N_2O emissions occur from nitrification and denitrification processes in manure management systems or managed soils owned or controlled by the reporting company. Direct N_2O emissions will vary based on the amount of nitrogen, type of nitrogen inputs, climate, aeration, as well as plant and microbial community composition.

Indirect N_2O emissions occur from nitrification and denitrification processes on lands or water bodies, potentially outside of the managed systems but due to nitrogen losses from the management system. Nitrogen can be lost to the atmosphere through volatilization of NH_3 or NO_x from N inputs to managed soils or combustion of fossil fuels and biomass. This volatilized nitrogen may later be deposited on other lands leading to nitrification and denitrification that generates indirect N_2O emissions. Nitrogen can also be lost through leaching or runoff, primarily in the form of NO_3^- in climates with greater precipitation. Such nitrogen losses to leaching and runoff can also undergo nitrification and denitrification on other lands or water bodies that generates indirect N_2O emissions.

Manure, urine and dung from livestock systems can have direct N_2O emissions from sites where their manure is processed or treated or lands where urine and dung are deposited, as well as indirect N_2O emissions from N losses from such systems. Section 19.2.2 provide guidance on direct and indirect N_2O emissions from livestock where manure is managed. Section 19.2.3 provides guidance on estimating direct and indirect N_2O emissions from livestock where manure is unmanaged.

N inputs to managed soils that are not directly utilized by plants can result in direct N_2O emissions on the lands where they are applied (see section 19.3.1 for calculation guidance) or indirect N_2O emissions from other N losses from such lands (see section 19.3.2 for calculation guidance).

Direct N_2O emissions should be accounted for and reported in scope 1 for the company that owns or controls the land or facilities where N_2O emissions occur (e.g., from cropland soils or manure management facilities), and in scope 3 for other companies in the value chain, both upstream (e.g., fertilizer manufacturers) or downstream (e.g., companies that purchase crops or other land-based products) of the lands or facilities where N_2O emissions occur. Following the GHG Protocol *Agricultural Guidance*, indirect N_2O emissions are reported in scope 1 for land managers or manure management operators, even though the emissions may occur outside of lands owned or controlled by the reporting company. Indirect N_2O emissions should also be accounted for in scope 3 for other companies in value chains with managed soils and/or livestock management, both upstream and downstream.

19.1.5 Life cycle impacts from agricultural inputs

This chapter covers only the emissions from sources on the land, rather than the full value chain GHG emissions of land-based products. Examples of relevant life cycle emissions for land-based products include:

- Upstream GHG emissions from fertilizer production (e.g., ammonia and nitric acid production)
- Upstream GHG emissions from the mining of agricultural inputs (e.g., phosphate, lime, potash)
- Upstream land management GHG emissions from feed production for livestock systems
- Downstream GHG emissions from refrigeration of biogenic products during transportation and distribution

[30] Tian et al., 2020

- Downstream GHG emissions from waste and wastewater treatment

Emissions relating to the full value chain of land-based products, including processing, refrigeration, transportation, distribution, storage, use, end-of-life and other stages beyond the farm gate are not included in this section. Accounting guidance on estimating such GHG emissions can be found in chapter 5 of the *Scope 3 Calculation Guidance*. Resources and databases with life cycle GHG emission factors are provided under the calculation tools and third party life cycle databases on the GHG Protocol website.

19.2 Emissions from livestock

Some livestock species emit CH_4 through enteric fermentation, CH_4 and N_2O (both directly and indirectly) through management of their manure and N_2O (both directly and indirectly) from livestock urine and dung directly deposited on grazing lands where manure is unmanaged. CO_2 emissions from livestock are not estimated because annual net CO_2 emissions from grazing and respiration are assumed to be zero (i.e., the CO_2 photosynthesized by plants consumed by livestock is quickly returned to the atmosphere as respired CO_2). A portion of the carbon is returned as CH_4 with a higher global warming potential, and for this reason CH_4 requires separate consideration. This section provides guidance on calculating CH_4 and N_2O emissions from livestock.

19.2.1 CH_4 emissions from enteric fermentation

CH_4 is produced in ruminant livestock (e.g., cattle, buffalo, sheep, goats) as a by-product of enteric fermentation, where carbohydrates are broken down by bacteria in the digestive tract. The amount of CH_4 that is produced per animal and per unit of output depends on several factors such as the type of animal, the quality and composition of feed, the animal breed, specific genetic characteristics, and the lifetime of the animal. The greatest source of enteric CH_4 is from cows raised for dairy and beef.

Companies that own livestock or manage the facilities or lands where livestock are raised should report enteric fermentation CH_4 emissions in scope 1. Companies in the value chain of animal products derived from livestock or that support livestock production (e.g., beef, dairy products, leather, feed suppliers etc.) but do not own or operate land or facilities where livestock are raised should report enteric fermentation CH_4 emissions in scope 3.

Methane emissions can be estimated using activity-based methods by multiplying the number of livestock for each animal type by an emission factor (see equation 19.1). Activity data on livestock can be obtained from various sources, including suppliers, government statistics and agricultural industry. For scope 3 accounting, additional conversion factors may be needed to convert from the amount of produced animal products back to the live animal populations or companies can apply emission factors developed specifically for the mass of animal products (e.g., emission factors in units of kg CO_2e/kg animal product). Livestock should be disaggregated by animal type, consistent with IPCC categorization: Cattle (dairy and other); Buffalo; Sheep; Goats; Camels; Horses; Mules and Asses; Deer; Alpacas; Swine; Poultry; and Other. Tier 2 country-specific emission factors should be used, where available; alternatively, default Tier 1 IPCC emission factors may be used.

Equation 19.1 **CH_4 emissions from enteric fermentation**

$$CH_4 = N_{(T)} \times EF_{(Enteric,T)} \times 10^{-3}$$

Description			Value
CH_4	=	CH_4 emissions in tonnes	Computed
T	=	Species / Livestock category	User input
N	=	Number of animals (head)	User input
EF	=	Emission factor for enteric fermentation (kg of CH_4 per head per year)	User input or default values

Source: Adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories,* Volume 4, Agriculture, Forestry and Other Land Use. Available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

If the data is available, companies may choose to develop a farm- or region-specific Tier 2 calculation that accounts for factors such as the feed composition and efficiency, feed digestibility, and farm or rangeland management. This information regarding the feed type can be used to calculate the net energy intake per day. Next, a methane conversion ratio converts this number into an "implied emission factor" of methane emitted per head. The methane conversion ratio may be available for a given farm or region. If the value is unavailable, the IPCC provides guidance to estimate it based on the type of management system for both developed and developing countries.

Another option is to apply national data from relevant countries that have country specific emission factors for average management practices. If properly justified, these figures can be applied and more accurate emission factors can be adopted based on national inventory reports (NIR) submitted to the UNFCCC.[31] To apply such Tier 2 enhanced characterization methods, companies need activity data relevant to their operations or value chain on the animal's gross energy intake and feeding characteristics including animal age, sex, typical animal mass, energy needed for maintenance, growth, activity, work, pregnancy and lactation, and dietary requirements. In case of large herds, procedures outlined in national inventories to model feed intake as a function of age may be adopted either for dairy or beef cattle.

19.2.2 CH_4 and N_2O emissions from manure management

Manure management releases both methane and nitrous oxide. The quantity of these emissions is based on the amount of manure produced, type of management system (e.g., slurry, dry lot, deep bedding), the frequency of manure removal, and whether waste is stored in a liquid or solid state. Methane is most readily emitted under anaerobic conditions when the density of animals is high in a barn or pen, manure is stored in liquid rather than solid form, and waste is left uncovered. Methane emission factors also vary based on climate, where warmer conditions have higher rates of emissions. Nitrous oxide emissions occur through a combination of nitrification and denitrification processes and increase for manures with higher nitrogen content, in systems where aeration is low and where manure is left uncovered.

Companies who own livestock where manure is managed or manage the facilities for manure treatment should report CH_4 and N_2O (both direct and indirect) emissions from manure management in scope 1. Companies in the value chain of animal products derived from or that support livestock production where manure is managed

[31] Available at https://unfccc.int/ghg-inventories-annex-i-parties/2021

(e.g., beef, dairy products, leather, feed suppliers etc.) but do not own or operate lands or manure management facilities should report CH_4 and N_2O (both direct and indirect) emissions from manure management in scope 3.

Calculating CH_4 emissions from manure management requires data on livestock by animal type and average annual temperature, in combination with relevant emission factors (see equation 19.2). Livestock numbers and categorization should be consistent with the method listed in section 19.2.1. Average annual temperature data can be obtained from international and national weather centers, as well as academic sources. Tier 2 country-specific temperature-dependent CH_4 emission factors should be used, where available; alternatively, Tier 1 default IPCC emission factors may be used.

Methane emissions from manure management depend primarily on the Methane Conversion Factor (MCF) and the daily Volatile Solids (VS) production of a certain animal. The MCF is based on the climate of the region (cool, temperate, or warm), and both methane and nitrous oxide depend on the management system (e.g., dry lot, slurry). This information allows for the calculation of an emission factor of methane per head. Tier 3 calculations would use these parameters at the farm level. However, a Tier 2 MCF and national management system information can be used to generate a country-level emission factor if the country of origin is known (which can be found in a country's National Inventory Report).

Equation 19.2 CH_4 emissions from manure management

$$CH_4 = (N_{(T)} \times EF_{(T)} \times 10^{-3})$$

Description			Value
CH_4	=	CH_4 emissions in tonnes	Computed
T	=	Species / Livestock category	User input
$N_{(T)}$	=	Number of animals for each livestock category	User input
$EF_{(T)}$	=	Emission factor for manure management (kg of CH_4 per head per year)	User input or default values

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Manure management takes place during the storage and treatment of manure before it is applied to land or otherwise used for feed, fuel, or construction purposes. To estimate N_2O emissions from manure management systems involves multiplying the total amount of N excretion (from all livestock categories) in each type of manure management system by an emission factor for that type of manure management system (see equation 19.3). This includes the following steps:

- Collect livestock data by animal type (T)
- Determine the annual average nitrogen excretion rate per head ($Nex_{(T)}$) for each defined livestock category T (see equation 19.4)
- Determine the fraction of total annual nitrogen excretion for each livestock category T that is managed in each manure management system S ($MS_{(T,S)}$)
- Obtain N_2O emission factors for each manure management system S ($EF_{(S)}$)
- For each manure management system type S, multiply its emission factor ($EF_{(S)}$) by the total amount of nitrogen managed (from all livestock categories) in that system, to estimate N_2O emissions from that manure management system

Equation 19.3 Direct N_2O emissions from manure management

$$N_2O = [\Sigma_S\,[\Sigma_T\,(N_{(T)} \times Nex_{(T)} \times MS_{(T),(S)})] \times EF_{(S)}] \times 44/28 \times 10^{-3}$$

N_2O	=	N_2O emissions in tonnes
S	=	Manure management system (MMS)
T	=	Livestock category
$N_{(T)}$	=	Number of animals for each livestock category
$Nex_{(t)}$	=	Annual N excretion for livestock category T, kg N per animal per year. *See Equation 10.4*
MS	=	Fraction of total annual nitrogen excretion managed in MMS for each livestock category
$EF_{(s)}$	=	Emission factor for direct N_2O-N emissions from MMS, kg N_2O-N per kg N in MSS
44/28	=	Conversion of N_2O-N emissions to N_2O emissions

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Equation 19.4 Annual N excretion rates from livestock

$$Nex_{(T)} = N_{rate(T)} \times TAM_{(T)} \times 10^{-3} \times 365$$

$Nex_{(T)}$	=	Annual N excretion for livestock category T, kg N per animal per year
$N_{rate(T)}$	=	Default N excretion rate, kg N per 1000kg animal per day
$TAM_{(T)}$	=	Typical animal mass for livestock category T, kg per animal

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Indirect N_2O emissions result from volatile nitrogen losses that occur primarily in the forms of NH_3 and NO_x. Calculation is based on multiplying the amount of nitrogen excreted from all livestock categories (see equation 19.4) and managed in each manure management system by a fraction of volatilized nitrogen (see equations 19.5 and 19.6). N losses are then summed over all manure management systems to estimate indirect N_2O emissions.

Equation 19.5 Indirect N_2O emissions due to volatilization of N from manure management

$$N_2O = (N_{volatilization\text{-}MMS} \times EF_4) \times 44/28 \times 10^{-3}$$

N_2O	=	Indirect N_2O emissions due to volatilization of N from manure management in tonnes
$N_{volatilization\text{-}MMS}$	=	Amount of manure nitrogen that is lost due to volatilization of NH_3 and NO_x, kg N per year. *See Equation 10.22*
EF_4	=	Emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, kg N_2O-N per kg NH_3-N and NO_x-N volatilized

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Equation 19.6 N losses due to volatilization from manure management

$$N_{volatilization\text{-}MMS} = \Sigma_S [\Sigma_T [(N_{(T)} \times Nex_{(T)} \times MS_{(T,S)}) \times (Frac_{GasMS} \times 10^{-2})_{(T,S)}]]$$

$N_{volatilization\text{-}MMS}$	=	Amount of manure nitrogen that is lost due to volatilization of NH_3 and NO_x, kg N per year
S	=	Manure management system (MMS)
T	=	Livestock category
$N_{(T)}$	=	Number of head of livestock per livestock category
$Nex_{(T)}$	=	Average N excretion per head of livestock category T, kg N per animal per year
$MS_{(T,S)}$	=	Fraction of total annual N excretion for each livestock category T that is managed in manure management system S
$Frac_{GasMS}$	=	Percent of managed manure nitrogen for livestock category T that volatilizes as NH_3 and NO_x in the manure management system S, %

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

19.2.3 N_2O emissions from urine and dung deposited on pasture, range and paddock

When livestock graze in the field, nitrogen is deposited on the soil through their waste. Some nitrogen is taken up by plant growth, while other forms of nitrogen are lost from the system. This includes direct N_2O emissions from the lands or indirect N_2O emissions from N losses to volatilization, leaching or runoff coming from the pasture, range and/or paddock livestock systems.

Companies who own or control lands used for pasture, range or paddock livestock systems or own livestock raised on grazing lands where manure is unmanaged, should report N_2O (both direct and indirect) emissions from urine and dung N deposited on pasture, range and paddock in scope 1. Companies in the value chain of animal products derived from or that support livestock production where manure is unmanaged (e.g., beef, dairy products, leather, feed suppliers etc.) but do not own or operate grazing lands should report N_2O (both direct and indirect) emissions from urine and dung N deposited on pasture, range and paddock in scope 3.

Companies may use equations 19.7 and 19.8 along with IPCC Tier 1 emissions factors disaggregated by livestock type and climate to estimate direct N_2O emissions from urine and dung N inputs.[32] Some countries (e.g., New Zealand) are conducting detailed research on N_2O emissions from nitrogen deposition accounting for local circumstances and may have Tier 2 emissions factors that can be applied. Farms operating in similar conditions and climate might be interested in identifying more accurate sources of information in case local circumstances matches these studies (proper justification must be provided before adoption of any results that may require third party verification for applicability outside the region of the study). Companies should use similar data and assumptions on the livestock populations, N excretion rates and manure management systems as those used in calculation other GHG emissions from livestock.

Companies should estimate indirect N_2O emissions from N losses from urine and dung deposited by grazing animals on pasture, range and paddock following the guidance in section 19.3.2.

[32] IPCC, 2019b (Volume 4, Chapter 11, Table 11.1)

Equation 19.7 Direct N_2O-N from urine and dung

$$N_2O\text{-}N_{PRP} = (F_{PRP,CPP} \times EF_{3PRP,CPP}) + (F_{PRP,SO} \times EF_{3PRP,SO})$$

$N_2O\text{-}N_{PRP}$	=	Direct N_2O-N emissions from urine and dung inputs to grazed soils, kg N_2O-N per year
F_{PRP}	=	Annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N per year (*Note:* the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively). *See Equation 10.16*
EF_{3PRP}	=	Emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, = kg N_2O-N (kg N input)-1; (*Note:* the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Equation 19.8 N in urine and dung deposited by grazing animals on pasture, range and paddock

$$F_{PRP} = \Sigma_T\,[(N_{(T)} \times Nex_{(T)}) \times MS_{(T,PRP)}]$$

F_{PRP}	=	Amount of urine and dung N deposited on pasture, range, paddock and by grazing animals, kg N per year
$N_{(T)}$	=	Number of head of livestock per livestock category
$Nex_{(T)}$	=	Average N excretion per head of livestock category T, kg N per animal per year
$MS_{(T, PRP)}$	=	Fraction of total annual N excretion for each livestock category T that is deposited on pasture, range and paddock

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

19.2.4 GHG emissions from aquaculture

Aquaculture, or 'fish farming,' is land-based in the sense that land is required to both house the ponds where the fish are bred and to produce feedstocks consumed by the fish. Aquaculture is responsible for a small but non-trivial amount of non-CO_2 greenhouse gases resulting from activities such as pond-fertilization, on-farm energy consumption, and applied nitrogen from feed production. However, the IPCC chapter on Agriculture, Forestry, and Other Land Uses identifies aquaculture emissions factors as a gap in knowledge and data.[33] There are a select few papers that provide life-cycle data for farmed fish, which companies with aquaculture in their supply chains may use.[34,35] However, data that disaggregate emissions between CO_2 and non-CO_2 sources are not readily available at this time, and so limits the possible guidance for this category.

[33] IPCC, 2014 (Chapter 11)

[34] MacLeod et al., 2020

[35] Gephart et al., 2021

19.3 Emissions from managed soils

Soil management across land uses (e.g., croplands, grasslands and forest lands) emits N_2O through nitrogen inputs to soils (e.g., nitrogen fertilizers, organic amendments, crop residues and soil organic matter mineralization) and CO_2 from lime and urea applications. Soil management also impacts soil carbon stock resulting in either biogenic net CO_2 removals or net biogenic CO_2 emissions from land management depending on soil carbon stock changes (see chapter 18 for calculation guidance). This section provides guidance on how to calculate CO_2 and N_2O emissions from managed soils.

19.3.1 Direct N_2O emissions from managed soils

Nitrogen is an essential macronutrient necessary for plant growth and is commonly controlled through soil management practices (e.g., residue and tillage management to mineralize organic forms of nitrogen available in crop residues and soil organic matter), crop rotations (e.g., including diverse rotations with N-fixing crops) or supplemental nitrogen application (e.g., applying synthetic nitrogen fertilizers or organic soil amendments) to increase soil fertility. Nitrogen inputs to soils can come from a variety of sources, each of which should be considered when estimating N_2O emissions from managed soils:

- Synthetic N fertilizers (e.g., urea, ammonium nitrate and other NPK fertilizer blends)
- Organic N inputs (e.g., manure, compost and organic soil amendments)
- Crop residues (e.g., N returned to the soil from corn stover left on the field)
- Soil organic matter mineralization (e.g., N mineralized due to land use change or soil tillage)
- Urine and dung deposited by livestock (e.g., N from sheep on pastures), see section 19.2.3
- Draining of organic soils (e.g., N mineralized due to peatland drainage), see section 19.3.3

Different crops in different regions require specific amounts of nitrogen. Nitrogen uptake by plants depends on the source, rate, placement and timing of N inputs. Matching plant nitrogen uptake with nitrogen application is often difficult. If additional nitrogen is added beyond what the crops require, this leads to denitrification and nitrification processes, which generate N_2O emissions among other N losses. These emissions may occur at the site of application, or they may occur indirectly if the nitrogen volatilizes to the atmosphere or leaches into a water source and is emitted elsewhere.

Companies who own or control lands where nitrogen is applied or made available through soil management (e.g., croplands, managed pastures or forest plantations), should report N_2O (both direct and indirect) emissions from managed soils in scope 1. Companies in the value chain of biogenic products or who supply agricultural inputs to lands with managed soils but do not own or control such lands (e.g., food or feed crop consumers, forest product consumers from managed plantations, fertilizer suppliers, etc.) should report N_2O (both direct and indirect) emissions from managed soils in scope 3.

Companies may use equation 19.9 through 19.13 based on IPCC Tier 1 methods along with global emission factors to estimate direct N_2O emissions from managed soils.[36] Companies should apply Tier 2 country or management specific emission factors where available from peer-reviewed publications, national inventory reports or internationally recognized research institutes. Where data is available companies may also use Tier 3 model-based approaches to estimate N_2O emissions from soils ensuring that all relevant N inputs are included in such estimates as well as indirect N_2O emissions. Companies should use similar data, methods and assumptions to estimate N_2O emissions from managed soils as those applied to estimates GHG emissions from livestock systems and soil carbon stock changes as described in section 19.1.3.

[36] IPCC, 2019b (Volume 4, Chapter 11)

Equation 19.9 for estimating direct N_2O emissions from managed soils is broken down by the different types of N inputs to soil including synthetic N fertilizers (F_{SN}), organic amendments (F_{ON}), crop residues (F_{CR}) and soil organic matter (F_{SOM}), where additional guidance on applying the IPCC equations is provided below.

Equation 19.9 Direct N_2O-N from managed soils

$$N_2O\text{-}N_{N\ inputs} = (F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \times EF_1 + (F_{SN} + F_{ON} + F_{CR} + F_{SOM})_{FR} \times EF_{1FR}$$

$N_2O\text{-}N_{N\ inputs}$	=	Direct N_2O-N emissions from N inputs to managed soils, kg N_2O-N per year
F_{SN}	=	Amount of synthetic fertilizer N applied to soils, kg N per year
F_{ON}	=	Amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (*Note:* If including sewage sludge, cross-check with Waste sector to ensure there is no double counting of N_2O emissions from the N in sewage sludge), kg N per year. *See Equation 10.14*
F_{CR}	=	Amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N per year. *See Equation 10.17*
F_{SOM}	=	Annual amount of N in mineral soils that is mineralized, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N per year. *See Equation 10.18*
EF_1	=	Emission factor for N_2O emissions from N inputs, kg N_2O–N (kg N input)-1
EF_{1FR}	=	Emission factor for N_2O emissions from N inputs to flooded rice, kg N_2O–N (kg N input)-1

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

N Inputs from Synthetic Fertilizer (F_{SN})

Companies should obtain activity data on the annual mass of N in synthetic fertilizers applied to soils from the operations or management records in land management units (e.g farm, pasture, plantation) where the fertilizers are applied to soils. Companies in the value chain that do not own or control such lands should collect such data from the land managers they source from or supply to depending on their location in the value chain and level of traceability. Where such data is not available, companies may use activity data on the average synthetic fertilizer N rates by cropping system in their sourcing region or country.

N Inputs from Organic Soil Amendments (F_{ON})

Companies should obtain activity data on the annual mass of N in organic soil amendments applied to soils from the operations or management records in land management units (e.g farm, pasture, plantation) where the N is applied to soils. Organic soil amendments include animal manure, sewage, compost or other organic materials applied to soils (equation 19.10). Lands where manure is applied should use similar data, methods and assumptions as the livestock and manure management systems where the manure was obtained from to estimate the amount of managed manure N available for soil application and fraction used for feed, fuel or construction as shown in equation 19.11. Where such data on organic soil amendments are not available, companies may use activity data on the average organic amendment N rates by cropping system in their sourcing region or country.

Equation 19.10 N from organic N additions applied to soils

$$F_{ON} = F_{AM} + F_{SEW} + F_{COMP} + F_{OOA}$$

F_{ON}	=	Amount of organic N fertilizer applied to soil other than by grazing animals, kg N per year
F_{AM}	=	Amount of animal manure N applied to soils, kg N per year. *See Equation 10.15*
F_{SEW}	=	Amount of total sewage N applied to soils, kg N per year
F_{COMP}	=	Amount of total compost N applied to soils, kg N per year
F_{OOA}	=	Amount of other organic amendments used as fertilizer, kg N per year

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Equation 19.11 N from animal manure applied to soils

$$F_{AM} = N_{MMS\_Avb} \times [1 - (Frac_{FEED} + Frac_{FUEL} + Frac_{CNST})]$$

F_{AM}	=	Amount of animal manure N applied to soils, kg N per year
N_{MMS_Avb}	=	Amount of managed manure N available for soil application, feed, fuel of construction, kg N per year
$Frac_{FEED}$	=	Fraction of managed manure used for feed
$Frac_{FUEL}$	=	Fraction of managed manure used for fuel
$Frac_{CNST}$	=	Fraction of managed manure used for construction

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

N Inputs from Crop Residues (F_{CR})

Companies should obtain activity data on the harvested area, crop dry matter yields and residue management systems based on operation and management records in the land management units (e.g farm, pasture, plantation) they own or control or in their value chain. N inputs from crop residues can be estimated using equation 19.12 with emission factors by crop type to determine the amount of dry matter left on the field and average N content in aboveground and belowground residues. Such Tier 1 emission factors are provided by IPCC national inventory guidance or Tier 2 emissions factors may be available from national inventory reports or peer-reviewed publications

Equation 19.12 N from crop residues and forage/pasture renewal

$$F_{CR} = \Sigma_T \, [Crop_{(T)} \times (Area_{(T)} - Area\ burnt_{(T)} \times CF) \times Frac_{Renew(T)} \times [R_{AG(T)} \times N_{AG(T)} \times (1 - Frac_{Remove(T)}) + R_{BG(T)} \times N_{BG(T)}]]$$

F_{CR}	=	Amount of N in crop residue returned to soils, kg N per year
$Crop_{(T)}$	=	Harvested dry matter yield for crop T, kg d.m. per hectare
$Area_{(T)}$	=	Total harvested area of crop T, hectare per year
$Area\ burnt_{(T)}$	=	Area of crop burnt, hectare per year
CF	=	Combustion factor
$Frac_{Renew(T)}$	=	Combustion factor
$RAG_{(T)}$	=	Ratio of above-ground residues dry matter ($AG_{DM(T)}$) to harvested yield for crop T. $R_{AG(T)} = AG_{DM(T)} \times 1000 / Crop_{(T)}$
$NAG_{(T)}$	=	N content of above-ground residues for crop T, kg N per kg dm
$Frac_{Remove(T)}$	=	Fraction of above-ground residues of crop T removed for purposes such as feed, bedding and construction, kg N per kg crop-N. If data for $Frac_{Remove(T)}$ is not available, assume no removal
$R_{BG(T)}$	=	Ratio of below-ground residues to harvested yield for crop T
$N_{BG(T)}$	=	N content of below-ground residues for crop T, kg N per kg dm
T	=	Crop or forage type

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

N Inputs from Soil Organic Matter Mineralization (F_{SOM})

Companies should estimate N inputs from soil organic matter mineralization based on the carbon to nitrogen ratio (C:N) of soil types and soil carbon stock losses from lands they own or control or in their value chain. To estimate soil carbon stock losses, companies should apply the guidance on accounting for carbon stock changes from land use change (chapter 17) and land management (chapter 18) and apply similar data, methods and assumptions as described in section 19.1.3.

Equation 19.13 N mineralized in mineral soils

$$F_{SOM} = \Sigma_{LU} [(\Delta C_{Mineral,LU} \times (1/R)) \times 1000]$$

F_{SOM}	=	Amount of N mineralized in mineral soils as a result of loss of soil carbon through change in land use or management, kg N per year
$\Delta C_{Mineral,LU}$	=	Loss of soil carbon for each land use type (LU), tonnes C (for Tier 1, this will be a single value for all land-uses and management systems)
R	=	C:N ratio of the soil organic matter
LU	=	Land-use and/or management system type

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

19.3.2 Indirect N_2O emissions from managed soils

Companies should estimate indirect N_2O emissions from N losses on managed land due to volatilization, leaching and runoff. When estimating indirect N_2O emissions from N losses on managed soils, companies should use the same activity data and assumptions used to estimate N inputs to managed soil as described in section 19.3.1 (i.e., N inputs from synthetic fertilizers, organic amendments, crop residues and soil organic matter mineralization), and N inputs from pasture, range and paddock as described in section 19.2.3 for livestock systems with unmanaged manure. Tier 1 emission factors from IPCC or Tier 2 country specific emission factors should be applied to estimate indirect N_2O emission.

Companies can estimate indirect N_2O emissions from N volatized from managed soils and deposited on other lands or waterbodies using equation 19.14. Companies can estimate indirect N_2O emissions from N lost to leaching or runoff on managed land where such processes occur using equation 19.15.

Equation 19.14 Indirect N_2O from atmospheric deposition of N volatilized from managed soils

$$N_2O_{(ATD)} = [(F_{SN} \times Frac_{GASF}) + ((F_{ON} + F_{PRP}) \times Frac_{GASM})] \times EF_4 \times 44/28 \times 10^{-3}$$

$N_2O_{(ATD)}$	=	Amount of N_2O produced from atmospheric deposition of N volatilized from managed soils in tonnes
F_{SN}	=	Amount of synthetic fertilizer N applied to soils, kg N per year
F_{ON}	=	Amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (*Note:* If including sewage sludge, cross-check with Waste sector to ensure there is no double counting of N_2O emissions from the N in sewage sludge), kg N per year. *See Equation 10.14*
F_{PRP}	=	Annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N per year (*Note:* the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively). *See Equation 10.16*
44/28	=	Conversion of N (N_2O-N) to N_2O
$Frac_{GASF}$	=	Fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x, kg N volatilized per kg N applied
$Frac_{GASM}$	=	Fraction of applied organic N fertilizer materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilizes as NH_3 and NO_x, kg N volatilized per kg N applied or deposited
EF_4	=	Emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, kg N_2O-N per kg NH_3-N and NO_x-N volatilized

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Equation 19.15 Indirect N_2O from managed soils in regions where leaching/runoff occurs

$$N_2O_{(L)} = [(F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) \times Frac_{LEACH-(H)} \times EF_5] \times 44/28 \times 10^{-3}$$

$N_2O_{(L)}$	=	Amount of N_2O produced from leaching and runoff of N additions to managed soils in regions where leaching / runoff occurs, in tonnes
$Frac_{LEACH-(H)}$	=	Fraction of all N added to/mineralized in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N per kg if N additions
EF_5	=	Emission factor for N_2O emissions from N leaching and runoff, kg N_2O-N per kg N leached and runoff

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

19.3.3 Direct N_2O emissions from drained organic soils

Organic soils and managed peatlands can generate significant N_2O emissions when they are oxidized through draining or other management impacting soil moisture, similar to N_2O emissions from soil organic matter mineralization on mineral soils. Where data is available, companies should estimate soil organic matter losses and the resulting N_2O emissions using Tier 3 methods following the guidance on land use change and land management accounting (see chapters 17 and 18) and apply similar data, methods and assumptions as described in section 19.1.3. Where data is not available companies can apply Tier 1 emission factors from IPCC guidance using equation 19.15 to estimate direct N_2O emissions from drained organic soils.

Equation 19.16 Direct N_2O-N from drained organic soils

$$N_2O\text{-}N_{OS} = (F_{OS,CG,Temp} \times EF_{2CG,Temp}) + (F_{OS,CG,Trop} \times EF_{2CG,Trop}) + (F_{OS,F,Temp,NR} \times EF_{2F,Temp,NR}) + (F_{OS,F,Temp,NP} \times EF_{2F,Temp,NP}) + (F_{OS,F,Trop} \times EF_{2F,Trop})$$

$N_2O\text{-}N_{OS}$	=	Direct N_2O-N emissions from managed inorganic soils, kg N_2O-N per year
F_{OS}	=	Area of managed/drained organic soils, ha (Note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)
EF_2	=	Emission factor for N_2O emissions from drained/managed organic soils, kg N_2O-N per hectare per year

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

19.3.4 CO_2 emissions from lime and urea application

Liming is used to reduce soil acidity and improve plant growth in managed soils. Adding carbonates to soils in the form of lime (e.g., calcic limestone ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$) leads to CO_2 emissions as the carbonate limes dissolve and release bicarbonate ($2HCO_3^-$), which evolves into CO_2 and water (H_2O). Companies can estimate CO_2 emissions from liming using equation 19.16 based on the mass of lime applied to soils they own or control or in their value chain. If lime is applied in a mixture with fertilizers, the proportion used should be estimated.

Equation 19.17 CO_2 emissions from liming

$$CO_2 = ((M_{Limestone} \times EF_{Limestone}) + (M_{Dolomite} \times EF_{Dolomite})) \times 44/12$$

CO_2	=	CO_2 emissions in tonnes
M	=	Amount of calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$), tonnes per year
EF	=	Emission factor, tonne of C per tonne of limestone or dolomite
44/12	=	Conversion of C stock changes to CO_2 emissions

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Equation 19.18 CO_2 emissions from urea fertilization

$$CO_2 = M \times EF \times 44/12$$

CO_2	=	CO_2 emissions in tonnes
M	=	Amount of urea fertilization, tonnes urea per year
EF	=	Emission factor, tonne of C per tonne of urea
44/12	=	Conversion of C stock changes to CO_2 emissions

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Urea ($CO(NH_2)_2$) is commonly applied to land as a nitrogen fertilizer and leads to a release of CO_2 in soils as the nitrogen is made available to plants. Companies can estimate CO_2 emissions from urea using equation 19.17 based on the mass of urea applied to soils they own or control or in their value chain.

Companies who own or control lands where lime or urea is applied, should report CO_2 emissions from managed soils in scope 1. Companies in the value chain of biogenic products that use lime and urea in production or who supply lime and urea to lands with managed soils but do not own or control such lands (e.g., food or feed crop consumers, urea manufacturing, limestone quarries, etc.) should report CO_2 emissions from managed soils in scope 3.

19.4 Emissions from biomass burning and fires

Fires, whether they are the result of natural disturbances or management activities, result in carbon stock losses to land based carbon pools and corresponding biogenic CO_2 emissions as well as other GHG emissions including CH_4 and N_2O. This section provides guidance to calculate CH_4, and N_2O emissions from biomass burning and fires. Accounting for the *Gross biogenic land CO_2 emissions* resulting from biomass burning and fires is included in chapter 18, however equation 19.19 can be used to also estimate gross CO_2 emissions.

Companies that own or control lands where fires or other forms of biomass burning on the land occur report CH_4 and N_2O emissions from biomass burning in scope 1. Companies with lands in their value both upstream or downstream where fires or biomass burning occurs report associated CH_4 and N_2O emissions from biomass burning in scope 3. Companies should account for CH_4 and N_2O emissions from fire using similar data and assumptions as used to estimate any carbon stock losses from fire.

Activity-based approaches are often applied to estimate GHG emissions from fire (i.e., gross biogenic CO_2, CH_4 and N_2O) based on the area of the fire, and the amount of fuel available for combustion within those area, a combustion factor (representing the proportion of the fuel combusted) and an emission factor. The mass of fuel available for combustion should include biomass, litter and deadwood, however litter and deadwood can be considered zero in cases where there is land use change.

Equation 19.19 GHG emissions from biomass burning

$$GHG_{BB} = A_B \times M_B \times C_F \times EF_{BB} \times 10^{-3}$$

Description		Unit	Source
GHG_{BB}	GHG emissions from biomass burning	(tonne GHG per year)	Calculated
A_B	Area of lands burnt in the reporting year	(hectares)	User input
M_B	Mass of fuel available for combustion	(tonnes per hectare)	Default value or user input
C_F	Combustion factor		Default value or user input
EF_{BB}	Emission factor for biomass burning	(g GHG per kg dry matter burnt)	Default value

Source: Adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories; Volume 4, Agriculture, Forestry and Other Land Use; Chapter 2 Generic Methodologies; Equation 2.27*. Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

The IPCC *Guidelines for National GHG Inventories* provides a generalized equation (equation 19.19) and default values to calculate GHG emissions from fire separately for each GHG.[37] Higher tier methods using country-specific activity data, remote sensing-based approaches for detecting fires, or model-based approaches to better estimate fuel availability, fire behavior, and carbon stock losses over time may also be applied to estimate GHG emissions from fire.

The sections below provide additional guidance by land use on how to calculate GHG emissions from fire.

- **Forest lands**: *IPCC Guidelines for National GHG Inventories* assume that at felling of a tree the non-merchantable components such as the bark, branches, foliage, etc. left on the ground are transferred to the dead organic matter pools. Any CH_4 and N_2O emissions from forest residue burning or prescribed burning on forest lands should be reported in accordance with the methods described above and reported within the relevant scope.
- **Grasslands**: Any CH_4 and N_2O emissions from incomplete combustion of prescribed burning on grassland should be reported in accordance with the methods described above and reported within the relevant scope.
- **Croplands**: In some regions, crop residues are burned during the harvest cycle, which releases CO_2, CH_4, and N_2O. Burning of crop residues or other biomass such as shrubs or trees on croplands generates carbon stock losses. Carbon stock losses from crop residue burning should be accounted for in the stock change-based reporting categories as changes in dead organic matter carbon stock changes or within biomass carbon stock changes for other biomass burning on croplands in accordance with the guidance in chapter 18. Any CH_4 and N_2O emissions from agricultural residue burning or other biomass burning on croplands should be reported in accordance with the methods described above and reported within the relevant scope. Companies should apply similar data and assumptions on burning of crop residues or other biomass when estimating N_2O emissions from N inputs from crop residues and soil carbon stock changes on croplands.

[37] 2019 Refinement to the 2006 IPCC Guidelines for National GHG Inventories Vol 4 Chapter 2 Section 2.4

Any carbon stock losses or GHG emissions from fires due to land clearing or other land use change events should be accounted for and reported as *Land use change emissions* in accordance with chapter 7.

19.5 Emissions from rice cultivation and flooded lands

19.5.1 CH_4 emissions from rice cultivation

Rice is commonly grown in flooded fields, primarily in tropical regions. This flooding creates anaerobic conditions, and microbes that decompose organic matter (e.g., from rice residues, soils or other organic soil amendments) in these conditions produce methane. The rates of methane production vary based on the water management regime, rice cultivar, climate, soil type and organic matter inputs to the rice production system. This section provides guidance on how to calculate CH_4 emissions from rice cultivation.

Companies that own or control lands where rice is cultivated, should report CH_4 emissions from rice cultivation in scope 1. Companies in the value chain of rice production that either purchase rice products or supply rice production systems but do not own or control such lands (e.g., rice processing companies, agricultural equipment suppliers for rice cultivation, etc.) should report CH_4 emissions from rice cultivation in scope 3. Companies that produce rice or are in rice production value chains must also report on other GHG emissions from managed soils associated with rice production as described in section 19.3.

To estimate emissions from rice production companies may apply equation 19.19 through 19.21 using IPCC Tier 1 emissions factors and activity data on rice production systems.[38] Activity data on the harvested area, cultivation period and other factors for selecting appropriate scaling factors should be based on operations or management records on lands where rice was produced. For scope 3 accounting where such data is not available companies can use data on the average yields or cultivation periods in the region or country, which should be available from a national statistics agency or agricultural research institutes.

Equation 19.20 CH_4 emissions from rice cultivation

$$CH_{4Rice} = \sum_{i,j,k}(EF_{i,j,k} \times t_{i,j,k} \times A_{i,j,k} \times 10^{-6})$$

CH_{4Rice}	=	Methane emissions from rice cultivation, Gg (i.e., 1000 metric tonnes) CH_4 per year
$EF_{i,j,k}$	=	Daily emission factor for i, j and k conditions, kg CH_4 per hectare per year
$t_{i,j,k}$	=	Cultivation period of rice for i, j and k conditions, number of days
$A_{i,j,k}$	=	Harvested area of rice for i, j and k conditions, hectares per year
i,j,k	=	Represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary (e.g. irrigated, rain-fed and upland)

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

[38] IPCC, 2019b (Volume 4, Chapter 5, Section 5.5)

Equation 19.21 Adjusted daily CH_4 emission factor for rice cultivation

$$EF_i = EF_c \times SF_w \times SF_p \times SF_o$$

EF_i	=	Adjusted daily emission factor for a particular harvested area (kg CH_4 per hectare per day)
EF_c	=	Baseline emission factor for continuously flooded fields without organic amendments (kg CH_4 per hectare per day)
SF_w	=	Scaling factor to account for the differences in water regime during the cultivation period
SF_p	=	Scaling factor to account for the differences in water regime in the pre-season before cultivation period
SF_o	=	Scaling factor should vary for both type and amount of organic amendment applied

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Where data is available, Tier 2 country- or management-specific baseline daily emission factors should be used and may be obtained from the national inventory reports, agricultural research institutions (e.g., FAO, International Rice Research Institute) and other peer-reviewed scientific literature. Where such emission factors are not available, the most recently published IPCC regional default values should be used.

Equation 19.22 Adjusted CH_4 emissions scaling factor for organic amendments

$$SF_o = (1 + \Sigma_i ROA_i \times CFOA_i)^{0.59}$$

SF_o	=	Scaling factor should vary for both type and amount of organic amendment applied
ROA_i	=	Application rate or organic amendment i, in dry weight for straw and fresh weight for others, tonne per hectare
$CFOA_i$	=	Conversion factor for organic amendment i

Source: Equation adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Volume 4 Agriculture, Forestry and Other Land Use available at: www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Where activity data specific to the rice cultivation practices, along with calibration data specific to their region, are available companies should apply Tier 3 model-based approaches (e.g., DNDC model) to estimate CH_4 emissions from rice cultivation. Where companies apply Tier 3 model-based approaches to estimate CH_4 emissions from rice cultivation, the same biogeochemical model should be applied to estimate N cycling and associated N_2O emissions from soils as well as soil carbon stock changes.

19.5.2 CH_4 emissions from reservoirs and other flooded lands

Hydropower production requires reservoirs to store and manage the flow of water used to generate kinetic energy. Similarly, other infrastructure for water management such as canals, ditches, etc. result in flooding of managed lands. These reservoirs and other flooded lands create anaerobic conditions, where microbes decompose organic matter and produce methane. The rate of methane production from reservoirs and other flooded lands varies based on the temperature, type of vegetation present, water body size and age. The age of a reservoir or other flood land is significant due to the higher rate of organic matter decomposition when land is first flooded, and therefore higher rate of methane emissions. Such higher rate of methane emissions is captured by the age-specific emission factors used in equation 19.23, where IPCC uses a threshold of 20 years.

This section provides guidance on how to calculate CH_4 emissions from reservoirs and other flooded lands relevant to a company's operations or value chain. Companies that own or control reservoirs, canals, ditches or other flooded lands report CH_4 emissions from such flooded land as scope 1 emission. Companies that purchase electricity from hydropower report CH_4 emissions from the hydropower reservoirs used to generate electricity as scope 2 emissions. Companies that otherwise have reservoirs, canals, ditches or other flooded land but do not own or control such lands report CH_4 emissions from such flooded land as scope 3 emissions.

To estimate methane emissions from reservoirs and other flooded lands companies can apply equation 19.23 using IPCC Tier 1 emission factors[39] and activity data. This Tier 1 approach estimates methane production from diffusion, ebullition, and downstream emissions. When estimating methane emissions from reservoirs, companies should use emission factors that are specific to reservoir age and climate. When estimating methane emissions from other constructed water bodies, companies should use emission factors specific to freshwater ponds, saline ponds, canals or ditches, and do not need to estimate downstream 95ethane emissions (i.e., apply a default of 0 for the ratio of total downstream CH_4 emissions). Companies can also scale emission factors to better reflect decomposition rates if information about average annual chlorophyll-a concentration value is available. For more information on emission factor selection and chlorophyll-a scaling, see chapter 7 of the 2019 IPCC refinement. To pursue a Tier 3 approach, companies can use a model of reservoir-specific methane emission rates, such as the Green House Gas Reservoir tool (G-res) model.[40]

Activity data on the total flooded surface area should be based on operations or management records on lands used for reservoirs or other flood lands. Companies should include drawdown zones or induction areas in the total flooded surface area used to calculate methane emissions. For scope 3 accounting where such data is not available, companies can use data on average surface area of reservoirs in the region or country, which should be available from national statistics services such as environmental agencies or peer reviewed research on the extent of reservoirs or other flooded lands.

Equation 19.23 CH_4 emissions from flooded lands

$$CH_{4_F} = \sum_f A_f \times EF_f \times (1 + 0.09)$$

Description		Unit	Source
$CH_{4,F}$	CH_4 emissions from flooded lands	(kg CH_4 per year)	Calculated
A_f	Total flooded surface area for flooded land type *f*	(hectares)	User input
EF_f	Emission factor for flooded land type *f*	(kg CH_4 per hectare per year)	Default value or user input
0.09	Ratio of total downstream CH_4 emissions to the total flux of CH_4 from the reservoir surface	(kg CH_4 downstream per kg CH_4 from reservoir)	Default value
f	Flooded land type		Subcategory

Source: Adapted from *2006 IPCC Guidelines for National Greenhouse Gas Inventories; Volume 4, Agriculture, Forestry and Other Land Use; Chapter 7 Wetlands; Equation 7.10*. Available at https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

[39] IPCC, 2019b (Volume 4, Chapter 7, Tables 7.9, 7.12 and 7.13)

[40] Available at https://g-res.hydropower.org

19.6 Other GHG emissions from land management

This section covers other GHG emissions (CO_2, CH_4 and N_2O) that occur land management. This chapter does not cover the full life cycle GHG emissions from supply chains of land-based products (e.g., emissions relating to processing, refrigeration, and other stages beyond the farm gate are not included in this section). Information on other emissions categories can be found in the *Scope 3 Calculation Guidance*, and life cycle emission factor datasets, which can be found in the database of existing methods and tools (see section 19.1.5).

19.6.1 GHG combustion emissions from on-site fuel and energy use

Companies should account for GHG combustion emissions associated with fuel and energy consumption from mobile farm or forestry machinery operations, stationary facility or equipment operations, transport within the farm or forest, irrigation and/or other related land management activities. Companies should disaggregate the fuel and energy consumption data by fuel sources associated with land management. Biogenic and non-biogenic fuel sources should be accounted for and reported separately.

Any GHG combustion emissions associated with fuel or energy consumption that occurs within the agricultural, forestry or other land management operations of the reporting company are reported in scope 1. Other companies in land management value chains both upstream and downstream (e.g., food and feed processors, forest product manufacturers, agricultural equipment suppliers) should report scope 3 emissions for the GHG combustion emissions associated with their relevant scope 3 activities. For example, consumer goods companies should account for the GHG emissions from fuel consumption and energy use on farms associated with the raw materials they purchase.

Companies should collect activity data on fuel and energy consumption by fuel type from the operations or management records on-site. Based on the types and quantities of fuel used, companies can use fuel-specific emission factors to estimate GHG emissions. Where available, companies should apply Tier 2 country specific emission factors to estimate CO_2, CH_4 and N_2O combustion emissions. Where such emission factors are not available companies may apply IPCC Tier 1 global emission factors by fuel type.

For fossil fuels (e.g., gasoline, diesel or natural gas) companies report CO_2, CH_4 and N_2O emissions from combustion in the relevant scope (scope 1, scope 2 or scope 3). For biogenic GHG emissions (e.g., biomass bioenergy, ethanol, biodiesel), biogenic CH_4 and N_2O emissions from combustion are accounted for and reported in the relevant scope (scope 1, scope 2 or scope 3), while biogenic CO_2 emissions from combustion are reported as biogenic combustion CO_2 emissions separately from the scopes (*subject to open question #1*).

19.6.2 Indirect (scope 2) GHG emissions from purchased energy

Some emissions from energy use for land management activities occur off-site where electricity, heating cooling or steam are purchased by the land managers. For example, energy required for irrigation pumps may be powered by electricity produced from off-site facilities with stationary combustion GHG emissions. Where the reporting company is the land manager and purchases energy, they should report the indirect GHG emissions in scope 2 in accordance with the *Scope 2 Guidance*. In cases where the reporting company is in the value chain of land managers that purchase energy, the company should report the indirect GHG emissions in the relevant scope 3 category in accordance with the *Corporate Value Chain (Scope 3) Standard*.

19.6.3 Other GHG emissions

Land management activities may result in other sources of GHG emissions depending on the land use, sector and geography. Other potential GHG emissions from on-site sources in operations or value chain with land management activities may include, for example, fugitive HFC and PFC emissions from air-conditioning and refrigeration, GHG emissions from waste management, and GHG emissions from wastewater treatment.

20

Accounting for Product Carbon Pools Calculation Guidance

Chapter 20: Accounting for Product Carbon Pools

Calculation Guidance

Chapter 9 provides requirements and guidance on accounting and reporting emissions and removals associated with product carbon pools. This chapter provides guidance on calculating the net product carbon stock change using the storage monitoring framework (section 20.1). It also includes calculation guidance for using storage discounting frameworks to calculate temporary product carbon storage in section 20.2. Section 20.3 provides guidance on calculating gross CO_2 emissions from products.

Reporting net removals with product storage is optional and is subject to open question #2 (chapter 6, box 6.3 and repeated in chapter 9, box 9.2).

Calculation guidance and methods for estimating land carbon stock changes associated with biogenic products are provided in chapter 18. Calculation guidance for removals with geologic carbon storage is described in chapter 21. Calculation guidance and methods for estimating technological removals associated with technologically removed CO_2 based products are provided in Annex A.

Sections in this chapter

Section	Description
20.1	Storage monitoring methods to account for net product carbon stock change
20.2	Storage discounting methods to account for temporary product carbon storage
20.3	Calculating gross CO_2 emissions from products

20.1 Storage monitoring methods to account for net product carbon stock change

This section provides guidance on calculating product carbon stock changes to account for *Net CO_2 emissions from product storage* and *Net removals with product storage*, using stock-change accounting methods.

If accounting for net emissions and net removals from **biogenic product carbon pools** using stock-change accounting, companies account for and report the annual net biogenic product carbon stock change converted to CO_2 and reported as:

- *Net CO_2 emissions from biogenic product storage* (when the carbon stock decreases) in scope 3 category 11 (use of sold products) or category 12 (end of life treatment of sold products), or
- Optionally: *Net biogenic removals with product storage* (when the carbon stock increases) in scope 3 category 11 (Use of sold products) or category 12 (End-of-life treatment of sold products) *(subject to open question #2, see chapter 9, box 9.2)*
- Other relevant product life cycle GHG emissions, including land emissions (chapters 7, 8, and 17-19).

If accounting for net emissions and net removals from **TCDR-based product carbon pools** using stock-change accounting, companies account for and report the annual net TCDR-based product carbon stock change converted to CO_2 and reported as:

- *Net CO_2 emissions from TCDR-based product storage* (when the carbon stock decreases) in scope 3 category 11 (Use of sold products) or category 12 (End-of-life treatment of sold products), or
- Optionally: *Net technological removals with product storage* (when the carbon stock increases) in scope 3 category 11 (use of sold products) or category 12 (end of life treatment of sold products) *(subject to open question #2, see chapter 9, box 9.2)*
- Other relevant product life cycle GHG emissions

Estimating annual net product carbon stock change

Stock-change accounting of the annual net product carbon stock change over time can be applied to the aggregate product carbon pool associated with all products sold by the reporting company to account for net CO_2 removals and emissions from product storage. Annual net product carbon stock change are estimated based on the modified version of the IPCC national GHG inventory accounting methods, as provided in equation 20.1.

Equation 20.1 Annual net product carbon stock change

$$\Delta C_{P,p} = C_{P,p,y+1} - C_{P,p,y}$$

Description		Unit	Source
$\Delta C_{P,p}$	Annual net product carbon stock change for product type *p*, sold by the reporting company in year *y*	(tonnes C per year)	Calculated
$C_{P,p,y+1}$	Product carbon stock for product type *p*, at the end of the year *y+1*	(tonnes C)	Calculated (eq. 20.2, 20.5)
$C_{P,p,y}$	Product carbon stock for product type *p*, at the beginning of the year *y*	(tonnes C)	User input
p	Product or material type		Subcategory
y	Year		Subcategory

Source: Equation adapted from *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories; Volume 4 Agriculture, Forestry and Other Land Use; Chapter 12 Harvested Wood Products; Equation 12.2* available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

Equation 20.1 can be applied to estimate *Net removals with product storage* and *Net CO_2 emissions from product storage* for product types that contain biogenic carbon or TCDR-based carbon. Product types with carbon derived from fossil materials (e.g., oil, natural gas, limestone, etc.) or product types containing a mix of carbon of fossil and biogenic origin must not include such fossil carbon in products when estimating net biogenic or TCDR-based product carbon stock changes as described below.

Net biogenic product carbon stock changes

Companies can estimate net biogenic product carbon stock changes where product types sold by the reporting company contain biogenic carbon (e.g., lumber, wood panels or bio-based plastics). The annual net biogenic product carbon stock change in the reporting year represents the annual losses from and annual gains to the aggregate biogenic product carbon pool associated with all biogenic products sold (in the reporting year or in past years) by the reporting company.

Where the annual net biogenic product carbon stock is increasing and companies meet the removals requirements, they may report net removals with biogenic product storage (see chapters 6 and 9 for details). Where the annual net biogenic product carbon stock change is decreasing, and companies have previously reported net removals with biogenic product storage they are required to report net CO_2 emissions from biogenic product storage (see chapter 9 for details).

Annual net biogenic product carbon stocks at the end of the reporting year can be estimated based on the decay of previously sold biogenic products and the new inputs of biogenic carbon to the aggregate biogenic product carbon pool from products sold by the company in the reporting year (equation 20.2). Depending on the data available, companies can convert between decay constants and half-lives for a given product type and its particular value chain following equation 20.3.

Equation 20.2 Biogenic products carbon stock calculation

$$\mathbf{C}_{\mathbf{P},p,y+1} = \left(\mathbf{C}_{\mathbf{P},p,y} \times e^{-\mathbf{k}_p}\right) + \left(\mathbf{M}_{p,y} \times \mathbf{f}_{\mathbf{BC},p,y} \times \frac{1 - e^{-\mathbf{k}_p}}{\mathbf{k}_p}\right)$$

Description		Unit	Source
$C_{P,p,y+1}$	Biogenic product carbon stock for product type *p*, at the end of the year *y+1*	(tonnes biogenic C)	Calculated
$C_{P,p,y}$	Biogenic product carbon stock for product type *p*, at the beginning of the year *y*	(tonnes biogenic C)	User input
k_p	Decay constant for product type *p*, specific to its particular value chain	(per year)	User input or default value
$M_{p,y}$	Mass of product type *p*, sold in year *y*	(tonnes product per year)	User input
$f_{BC,p,y}$	Fraction of biogenic carbon in product type *p*, sold in year *y*	(tonnes biogenic C per tonnes product)	User input or default value
e	2.718 (mathematical constant)		Constant
p	Product or material type		Subcategory
y	Year		Subcategory

Source: Equation adapted from *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories; Volume 4 Agriculture, Forestry and Other Land Use; Chapter 12 Harvested Wood Products; Equation 12.2* available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

Equation 20.3 Product decay constant and its relation to product half-life

$$\mathbf{k}_p = \frac{ln(2)}{\mathbf{HL}_p}$$

Description		Unit	Source
k_p	Decay constant for product type *p*, specific to its particular value chain	(per year)	Calculated
HL_p	Average half-life for product type *p*, specific to its particular value chain	(years)	User input
p	Product or material type		Subcategory

Source: Equation adapted from *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories; Volume 4 Agriculture, Forestry and Other Land Use; Chapter 12 Harvested Wood Products; Equation 12.2* available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

The biogenic product carbon stock for biogenic product type *p,* at the beginning of the year *y* ($C_{P,p,y}$) should be estimated based on the previous year's calculations, starting from a base year. Companies should estimate the base year biogenic product carbon stock for each biogenic product type using historical data representing the mass of biogenic carbon in sold products and the emissions from those carbon pools in the inventory base year or period. Where no net CO_2 removals with biogenic product storage were previously reported by a company, omitting calculations from years prior to the base year or period will not lead to any overestimation of the carbon storage impact of a company's value chain.

Where data on the biogenic product carbon stock in the base year or period is not readily available, companies can approximate the base year biogenic product carbon stock using a 5-year reference period representative of historic production in the base year or period and a decay constant following equation 20.4.

Equation 20.4 Biogenic products carbon stock estimation based on historical data

$$C_{P,p,y_b} = \frac{\sum_{i=y_1}^{y_5} M_{p,y} \times f_{BC,p,y} \Big/ 5}{k_p}$$

Description		Unit	Source
C_{P,p,y_b}	Biogenic product carbon stock for product type *p*, at the beginning of the base year y_b	(tonnes biogenic C)	Calculated
$M_{p,y}$	Mass of product type *p*, sold in year *y* of the 5-year reference period	(tonnes product per year)	User input
$f_{BC,p,y}$	Fraction of biogenic carbon in product type *p*, sold in year *y* of the 5-year reference period	(tonnes biogenic C per tonnes product)	User input or default value
k_p	Decay constant for product type *p*, specific to its particular value chain	(per year)	User input or default value
p	Product or material type		Subcategory
y	Year of the 5-year reference period		Subcategory

Source: Equation adapted from *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories; Volume 4 Agriculture, Forestry and Other Land Use; Chapter 12 Harvested Wood Products; Equation 12.4* available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

Net TCDR-based product carbon stock changes

Companies can estimate net TCDR-based product carbon stock changes where product types sold by the reporting company contain carbon derived from technological CO_2 removal processes (e.g., direct air capture CO_2-cured cement or direct air capture CO_2-based plastics). The annual net TCDR-based product carbon stock change in the reporting year represents the annual losses from and annual gains to the aggregate TCDR-based product carbon pool associated with all TCDR-based products sold (in the reporting year or in past years) by the reporting company.

Where the annual net TCDR-based product carbon stock change is increasing and companies meet the removals requirements, they may report *Net technological removals with product storage* (see chapters 6 and 9 for details). Where the annual net TCDR-based product carbon stock change is decreasing, and companies have previously reported *Net technological removals with product storage* they are required to report *Net CO_2 emissions from TCDR-based product storage* (see chapter 9 for details).

Annual net TCDR-based product carbon stocks at the end of the reporting year can be estimated based on the decay of previously sold TCDR-based products and the new inputs of TCDR-based carbon to the aggregate TCDR-based product carbon pool from products sold by the company in the reporting year, as estimated in equation 20.5.

Equation 20.5 TCDR-based products carbon stock calculation

$$C_{P,p,y+1} = \left(C_{P,p,y} \times e^{-k_p}\right) + \left(M_{p,y} \times f_{TCDR,p,y} \times \frac{1 - e^{-k_p}}{k_p}\right)$$

Description		Unit	Source
$C_{P,p,y+1}$	TCDR-based product carbon stock for product type *p*, at the end of the year *y+1*	(tonnes TCDR-based C)	Calculated
$C_{P,p,y}$	TCDR-based product carbon stock for product type *p*, at the beginning of the year *y*	(tonnes TCDR-based C)	User input
k_p	Decay constant for product type *p*, specific to its particular value chain	(per year)	User input or default value
$M_{p,y}$	Mass of product type *p*, sold in year *y*	(tonnes product per year)	User input
$f_{TCDR,p,y}$	Fraction of carbon derived from technological CO_2 removal processes in product type *p*, sold in year *y*	(tonnes TCDR-based C per tonnes product)	User input or default value
e	2.718 (mathematical constant)		Constant
p	Product or material type		Subcategory
y	Year		Subcategory

Source: Equation adapted from *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories; Volume 4 Agriculture, Forestry and Other Land Use; Chapter 12 Harvested Wood Products; Equation 12.2* available at: https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html

The TCDR-based carbon stock for TCDR-based product type *p,* at the beginning of the year *y* ($C_{P,p,y}$) **should** be estimated based on the previous year's calculations, starting from a base year or period. Companies should estimate the base year TCDR-based product carbon stocks using historical data representing the mass of carbon derived from technological CO_2 removal processes in first year when TCDR-based products were sold.

20.2 Storage discounting methods to account for temporary product carbon storage

This section provides guidance on storage discounting methods to account for temporary product carbon storage. Storage discounting methods estimate the climate impact of storing carbon based on ex-ante assumptions regarding the duration of storage, as opposed to ongoing monitoring of annual net product carbon stock change.

Tonne-year accounting is one of the more readily applicable storage discounting methods that may be used to estimates the fraction of radiative forcing avoided during a given time horizon. Tonne-year accounting and other storage discounting methods (e.g., dynamic LCA methods[41 ,2,3]), however, do not accurately reflect the impact of a company's activities on cumulative CO_2 emissions and the remaining carbon budget, because emissions occurring after the chosen time horizon are not accounted for.

If reported, temporary product carbon storage calculated using tonne-year accounting is reported outside of the scopes in the separate reporting category "Temporary product carbon storage" *(subject to open question #2, chapter 9, box 9.2)*.

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[41] Levassuer et al., 2010

Companies applying tonne-year accounting approaches should use either the Lashoff tonne-year method or the ILCD 1% method. Additional guidance on methods for estimating the product storage using the two approaches are provided below:

- **Lashoff tonne-year method:** The Lashoff method estimates the tonne-year characterization factor (in tonne-years) of delaying CO_2 emissions until the end of sequestration period.[42] This method estimates the climate impact of delaying emissions based on the difference between the integrals within the time horizon to the integral pushed beyond the time horizon.
- **ILCD tonne-year approximation**: The ILCD method can be applied as a linear approximation of the Lashoff tonne-year method for a 100-year time horizon[43]. The ILCD method suggests that for a 100-year time horizon, the equivalent GWP_{100} metric of storage is 0.01 per year per tonne of product.[44]

Temporary product carbon storage can be calculated using equation 20.6, based on a temporary storage factor representing the climate impact of delaying one tonne of CO_2 emissions until the end of the sequestration period over a time horizon of 100 years or more. The temporary storage factor should be estimated based on the years carbon in a given product type is stored, following either the Lashoff tonne-year method or the ILCD tonne-year approximation.

Equation 20.6 Temporary biogenic product carbon storage

$$\mathrm{TS}_{\mathrm{P},p} = \mathrm{M}_{p,y} \times \mathrm{f}_{\mathrm{BC/TCDR},p,y} \times \mathrm{f}_{\mathrm{Y},p} \times \mathrm{f}_{\mathrm{TS},p} \times \frac{44}{12}$$

Description		Unit	Source
$TS_{P,p}$	Temporary product carbon storage for product type *p*	(tonnes CO_2-eq)	Calculated
$M_{p,y}$	Mass of product type *p*, sold in year *y*	(tonnes product sold per year)	User input
$f_{BC/TCDR,p,y}$	Fraction of carbon derived from biogenic carbon or technological CO_2 removal processes in product type *p*, sold in year *y*	(tonnes biogenic or TCDR-based C per tonnes product)	User input or default value
$f_{Y,p}$	Yield factor for product type *p*, the fraction of biogenic or TCDR-based carbon effectively transferred to storage downstream in the value chain	(tonnes C stored per tonnes C sold)	
$f_{TS,p}$	Temporary storage factor for product type *p*, represents the climate impact of temporarily storing carbon in products based on the years carbon is stored	(tonnes CO_2-eq per tonnes biogenic or TCDR-based C stored)	Default value (table 20.1)
p	Product or material type		Subcategory
y	Year		Subcategory
44/12	Conversion from C to CO_2		Constant

[42] Fearnside et al., 2000

[43] Brandão and Levasseur, 2010

[44] European Commission – Joint Research Centre – Institute for Environment and Sustainability, 2010

Table 20.1 shows the temporary storage factor (0 to 1) for various storage durations using a time-horizon of 100 years. For more information regarding the Lashoff tonne-year method or the ILCD tonne-year approximation, refer to ILCD handbook[45] or Brandão and Levasseur, 2010.[46]

Table 20.1 Temporary storage factor: tonne-year accounting methods

Storage period (Years)	Temporary storage factor	
	ILCD tonne-year approximation	Lashoff tonne-year method*
20	0.20	0.150
30	0.30	0.229
40	0.40	0.312
50	0.50	0.399
60	0.60	0.493
70	0.70	0.594
80	0.80	0.706
90	0.90	0.833
100	1.00	1.000

* *Source:* IPCC, 2000 (Chapter 2.3.6.3)

20.3 Calculating gross CO_2 emissions from products

As described in chapter 9, companies are required to account for gross CO_2 emissions from biogenic and TCDR-based product carbon pools, including all direct and indirect CO_2 emissions throughout the product life cycle (i.e., cradle to grave). As products move through the value chain, their carbon content can be emitted during different stages of their life cycle, such as during production, processing, use phase, or end-of-life treatment (e.g., degradation of harvested wood products (HWP) in landfill).

Reporting requirements for gross CO_2 emissions are as follows:

For biogenic products:

- Required: Gross CO_2 emissions from biogenic product carbon pools, reported under *Gross biogenic product CO_2 emissions* (not aggregated with net emissions) and organized by the relevant scope 1, scope 2 or scope 3 categories based on where they occur within the value chain to differentiate direct and indirect gross emissions (see table 5.8).
- Optional: *Gross biogenic land CO_2 removals* and *Gross biogenic land CO_2 emissions* (see chapters 8 and 18)

For TCDR-based products:

[45] Available at https://doi.org/10.2788/94987

[46] Available at https://doi.org/10.2788/21592

- Required: Gross CO_2 emissions from TCDR-based product carbon pools, reported under *Gross TCDR-based product CO_2 emissions* (not aggregated with net emissions) and organized by the relevant scope 1, scope 2 or scope 3 categories based on where they occur within the value chain to differentiate direct and indirect gross emissions (see table 5.8).
- Optional: *Gross technological CO_2 removals* (see Annex A)

Equations 20.7 and 20.8 provide methods for calculating gross CO_2 emissions from biogenic products and TCDR-based products, respectively.

Equation 20.7 Gross biogenic product CO_2 emissions

$$GE_{BP} = M \times f_B \times EF_{CO_2}$$

Description		Unit	Source
GE_{BP}	Gross biogenic product CO_2 emissions	(tonnes biogenic CO_2)	Calculated
M	Mass of biogenic product	(tonnes product sold per year)	User input
f_B	Fraction total product carbon of biogenic origin	(tonnes biogenic C per tonnes product C)	User input or default value
EF_{CO_2}	CO_2 emission factor, based on the type of the product and application (e.g., CO_2 emission factor of open combustion of biomass)	(tonnes CO_2 per tonnes product)	User input or default value

Equation 20.8 Gross TCDR-based product CO_2 emissions

$$GE_{TCDR} = M \times f_{TCDR} \times EF_{CO_2}$$

Description		Unit	Source
GE_{TCDR}	Gross TCDR-based product CO_2 emissions	(tonnes TCDR-based CO_2)	Calculated
M	Mass of TCDR-based product	(tonnes product sold per year)	User input
f_{TCDR}	Fraction total product carbon originating from technological carbon dioxide removal processes	(tonnes TCDR-based C per tonnes product C)	User input or default value
EF_{CO_2}	CO_2 emission factor, based on the type of the product and application (e.g., CO_2 emission factor of open combustion of TCDR-based fuel)	(tonnes CO_2 per tonnes product)	User input or default value

Emission factors reflect the CO_2 emissions released to the atmosphere at combustion, decomposition or other process, by type of product/material. Companies should use the most representative emission factors for each type of product or material based on the specific type of product or material, its carbon content, and according to the relevant process (e.g., stationary combustion, mobile combustion, decomposition in landfills, etc.).[47]

For products containing carbon from different origins, companies should determine the fraction of the total product carbon content that is of biogenic or TCDR origin. For example, for a fuel blend with 10% ethanol, the

[47] Emission factors can be found in the IPCC *Emission Factor Database* (https://www.ipcc-nggip.iges.or.jp/EFDB/main.php), IPCC *Guidelines for National Greenhouse Gas Inventories*, (https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html), GHG Protocol website (https://ghgprotocol.org/calculation-tools), life cycle inventory databases, and other sources in the List of land sector calculation tools and resources available at https://ghgprotocol.org/land-sector-and-removals-guidance.

fraction of total product carbon that is of biogenic origin would be the biogenic C content of the ethanol * 0.10 / total product C content of the fuel.

In most cases, the sum of gross CO_2 emissions from product carbon pools corresponds to the emissions of the entire carbon content of the product carbon pools owned or sold by the reporting company (unless, for example, the product carbon content is stored in geologic storage).

Chapter 8 and 18 provide guidance on calculating *Gross biogenic land CO_2 emissions and removals*, while chapter 10 provides guidance on calculating *Gross technological CO_2 removals* stored in TCDR-based products.

21

Accounting for Geologic Carbon Pools Calculation Guidance

Chapter 21: Accounting for Geologic Carbon Pools

Calculation Guidance

This chapter provides calculation guidance on monitoring and quantification methods related to geologic storage pathways including estimating inputs to and emissions from geologic reservoirs.

For accounting requirements and guidance related to geologic storage, refer to chapter 10.

Sections in this chapter

Section	Description
21.1	Introduction to geologic carbon pools
21.2	Calculation guidance and methods for geologic storage pathways

21.1 Introduction to geologic carbon pools

This section provides background on geologic reservoirs and injection (section 21.1.1), geologic carbon storage monitoring (section 21.1.2), and ownership and control of geologic storage (section 21.1.3).

21.1.1 Geologic reservoirs and injection types

Geological storage sites must meet the following specifications:

- Formations have enough porosity to provide the capacity to store the CO_2
- Pores in the rock are sufficiently connected and so provides permeability to accept the CO_2 at the rate it is injected, to allow the CO_2 to move and spread out within the formation
- Formations have a (physical and/or chemical) trapping mechanism to contain the CO_2 and prevent it from migrating to the surface

Fluids (water, brine, oil gas, and CO_2) are naturally stored in the deep subsurface, below and isolated from potable water. A century of experience with the extraction and injection of fluids, 0.8 km - 4 km below the land or sea surface, provides the basis for technologies that inject CO_2 into geologic reservoirs.

Table 21.1 presents the subsurface reservoirs that have been tested and developed for carbon storage, which fall into three major categories.

Table 21.1 Subsurface reservoirs for geologic carbon storage

Reservoirs for geologic storage	Examples
Sedimentary rocks with intergranular porosity	• Saline aquifers • Depleted oil or gas reservoirs
Sedimentary rocks that have significant CO_2 reactivity where flow occurs through fractures	• Coal seams • Organic-rich shales
Mafic or ultra-mafic rocks feasible for CO_2 mineral storage	• Volcanic rocks • Plutonic rocks

Geological storage can be further distinguished by the phase under which CO_2 is injected into the geologic formation (see table 21.2). The requirements of the geological storage reservoir and monitoring program should reflect the specifications needed for the CO_2 injection to ensure secure and permanent storage.

Table 21.2 CO_2 injection methods and their specifications for carbon storage in geologic reservoirs

CO_2 injection methods	Specifications needed for carbon storage
Supercritical CO_2 injection	• Injected at a reservoir depth to ensure supercritical state (e.g., typically greater than 800m). • Storage achieved through physical trapping to prevent buoyancy driven upward flow.
Dissolved CO_2 injection	• Amount of CO_2 injected limited by the maximum solubility of CO_2 in the solvent. • Injected at a reservoir depth to ensure the CO_2 remains in solution (e.g., typically greater than 400m). • Storage achieved through immediate solubility trapping provided the injection of CO_2 meets specified requirements.

The following sections provide a general description of the different subsurface reservoirs for geological carbon storage that have been tested and verified.

Sedimentary rocks with intergranular porosity

Sedimentary rocks with intergranular porosity store fluids principally in pores between mineral grains that are larger than a nanometer in size. Mineral grains can be quartz dominated (known as sandstone), $CaCO_3$- or $MgCO_3$-dominated (known as carbonate rocks), or mixtures of these and other minerals. These rocks are often further classified by the fluids they contain. If the pore fluids are fresh water the rock units are known as freshwater aquifers, which are mostly protected resources into which injection is prohibited. Freshwater aquifers are found in settings near the surface, most commonly at depths of less than 1000m but can be deeper in some areas. Below the depth to which freshwater circulates and at which CO_2 becomes dense (generally >800m), the rock units are classified as deep saline aquifers or saline reservoirs. Rock units that contain hydrocarbons (oil or gas) are known as hydrocarbon reservoirs or fields. Hydrocarbon reservoirs are known as depleted hydrocarbon reservoirs when they reach the end of economic life. CO_2 storage in both deep saline aquifers and depleted hydrocarbon reservoirs is a proven technology that has completed testing for CO_2 storage, validation through large-scale deployment and is currently in the commercial deployment stage.

The CO_2 storage mechanisms for sedimentary rocks with intergranular porosity include trapping CO_2 beneath a non-transmissive, ultra low-permeability confining system that prevents upward and outward migration of buoyant CO_2, capillary trapping which results in trapping of the non-wetting CO_2 as snapped-off "bubbles" unable to move through the small spaces between the grains, and CO_2 dissolved into brine or absorbed onto organic constituents in the rock. Some CO_2 may be trapped as new minerals precipitated from solution.

At depletion, oil fields still contain a significant fraction of the original oil which is trapped in the pores by capillary forces. This trapped oil can be extracted by injecting materials that interact with oil and make it mobile. This process is known as enhanced oil recovery (EOR). Under some common reservoir conditions CO_2 is the most favorable fluid to recover additional oil. During production mixtures of oil, CO_2, oil-CO_2 solution, and brine are brought to the surface. At surface pressure CO_2 separates from oil and brine and for both economic and environmental reasons (as the CO_2 is usually impure and cannot be vented), the CO_2 is cleaned, compressed and reinjected. The CO_2 that is injected for EOR is therefore retained in the reservoir in long-term isolation from the atmosphere, trapped by the storage mechanisms as other porous rocks.

Despite the recover and retention of injected CO_2 within the EOR system, the full life cycle of the produced oil or natural gas must be considered to determine the net CO_2 flux of the CO_2 EOR operation from the geologic reservoir from a GHG management context.[48] Where the net geologic carbon stock change is positive the EOR can provide climate benefits but where it is negative (i.e., carbon removed from the reservoir in the form of produced oil or natural gas is greater than CO_2-C injected in the reservoir) it can lead to net CO_2 emissions from geologic storage. Chapter 10 section 10.1.3 provides requirements and guidance on life cycle accounting for geologic storage pathways with enhanced oil and gas recovery, and section 21.2.4 provides for calculation guidance for estimating the carbon losses from EOR.

Sedimentary rocks where flow occurs through fractures

Sedimentary rocks where flow occurs through fractures are considered for storage, especially in rocks that have significant reactivity to CO_2 because of high organic content. CO_2 is absorbed onto the surfaces of many types of organic materials that are found in coal, lignite and organic-rich shales. In these settings, the CO_2 is able to enter via the fracture network but as it flows past organic materials it is trapped. The trapping mechanism is via absorption on surfaces. Fractures can be either natural (such as the cleat of coal) or man-made as part of unconventional hydrocarbon production. This type of storage has been tested, but large-scale deployment of CO_2 storage in sedimentary rocks where flow occurs through fractures is far less than deployment in sedimentary rocks with intergranular porosity.

Mafic or ultra-mafic rocks

Mafic or ultra-mafic rocks are rich in iron, magnesium, calcium or other divalent cations, and are well known to react with CO_2. Such reactions are the natural weathering process that operates as part of the carbon cycle. This process can be imitated and accelerated by the injection of dissolved CO_2 into such favorable rock formations. Storage of the injected CO_2 does not rely on structural, stratigraphic, or residual CO_2 trapping, instead CO_2 is stored primarily by dissolving the CO_2 through solubility trapping. The water-dissolved CO_2 forms a weak acid which reacts with the rock formation and releases cations to the water phase leading to the saturation of carbonate minerals such as calcite, magnesite, and/or siderite in the pore water (Ca, Mg or Fe-carbonates). This results in the precipitation of solid carbonate minerals within pores and fractures. Once the CO_2 is mineralized it

[48] Núñez-López et al, 2019

is stable over geological time scales. This trapping mechanism favors non-sedimentary rocks such as basalts and other mafic and ultra-mafic rocks, expanding the areas where geologic storage is feasible. In situ mineralization results in a negligible risk of the CO_2 migrating back to the atmosphere both in the short term (due to the dissolution of CO_2 and the density-related inhibition of surface migration) and the long term (due to conversion into carbonate minerals).

Box 21.1 Examples of geologic storage

Multiple millions of tons per year of CO_2 have been injected for enhanced oil recovery (EOR) since 1972 (SACROC unit Wasson Field Texas) and, since 1996, for storage of CO_2 to avoid release to the atmosphere (Sleipner project, Norwegian North Sea). Additional projects have followed and the feasibility and effectiveness of these projects is widely documented (see GCCSI world status report for project-by project details).[49]

Mineral storage in mafic rocks has been demonstrated in Iceland and the United States where CO_2 is dissolved and injected into a basaltic reservoir where rapid mineralization occurs. Further studies and pilots are underway to demonstrate the potential of mineral storage in other geological settings (igneous rocks such as peridotite, andesite, etc.) and to assess the feasibility of using seawater as the solvent. CO_2 mineral storage is now in the commercial deployment stage.

21.1.2 Geologic carbon storage monitoring

Storage duration in geological formation aims to be permanent. Secure geologic storage is possible with the correct characterization and modeling of the natural system that will retain the CO_2 and design of engineered systems compatible with retaining carbon in that reservoir. Where such characterization and operations are done properly, this process results in zero CO_2 losses from geologic storage (defined as less than 1% of the total injected mass lost over 100 to 1000 of years).[50] The most likely pathway for CO_2 loss is via an injection or recovery well that was not properly completed to isolate subsurface zones from each other and from the surface. Such failed wells provide a pathway for direct transmission of CO_2 from the reservoir to the surface. Such leakage should be fairly apparent and the failed well repaired. Losses from worst case scenarios where CO_2 losses are not detected and repaired still constitute a small share of CO_2 emissions relative to the rate at which CO_2 is injected into the reservoir, because of limits to the rate at which CO_2 can escape along such pathways (e.g., wellbore and porous media flow limits and pressure decline). However, leakage through faults can occur as well.

Monitoring is necessary to ensure the correct characterization, modeling and operation of the storage system and that the predicted levels of storage permanence are attained. The primary means of confirming the storage performance is by comparing observations to models of high CO_2 retention. If an error is found in these assumptions, a prudent operator or regulator can modify operations and mitigate that problem to avoid any losses before they occur (e.g., accept less CO_2 in a problematic well and direct more CO_2 into an alternate zone). In a worst case scenario where all barriers to leakage fail, the estimated CO_2 losses would be much less than the total CO_2 injected. Direct measurement for detection of leakage and associated fugitive CO_2 emissions can also be deployed, with highest sensitivity attained in near-static deep environments. For example, a zone above the injection horizon can be monitored for pressure or other changes that would be indicative of losses from the storage zone.

[49] Available at https://www.globalccsinstitute.com/

[50] National Academies of Sciences, Engineering, and Medicine, 2019

Models are also used to design monitoring, such that detection of no CO_2 along potential escape pathways near wells is strong evidence of no leakage above the monitoring design threshold. Direct detection of CO_2 in shallow environments such as groundwater, soil atmosphere, or ocean have been developed and are available. However, these settings are active both in terms of CO_2 respiration and uptake and in terms of dynamic physical process (weather, climate, land use, fluid movements etc.). Detection of CO_2 leakage into such dynamic environments is attenuated, delayed, and difficult to separate from background. Therefore, near surface detection or quantification methods may be best used in a targeted manner, for example, if a release has occurred or is suspected.

21.1.3 Ownership and control of geologic storage

The operator of a geological storage reservoir is the entity that holds a well permit or license, approved for CO_2 storage by the relevant authorities of the jurisdiction(s), which commonly includes:

- Proof of the technical competence of the operator
- Characterization of the storage complex
- Specification related to CO_2 to be injected (total quantity, composition, pressure and temperature)
- Assessment of the security of the storage, as well as preventive and corrective measures plan in case of leakage or irregularities
- Monitoring plan and post closure plan
- Proof of financial security

The authority to issue a geological storage permit for CO_2 is typically managed by the jurisdiction and should include an integrated risk assessment that identifies, mitigates, and manage risks and uncertainties to ensure the safety of any CO_2 storage site (i.e., ensures secure storage, minimizes risks of fugitive CO_2 emissions from leakage, and requires adequate remediation if any damage occurs). Both the geological storage reservoir and the injection facilities should be covered in such permit.

The geologic storage permit should cover the full life cycle of the project (i.e., development, operations, closure and, if covered by regulations, transfer of liabilities to the state). From the start of injection up to the cease of injection and closure, the following should be performed by the geologic storage operator:

- Site inspections
- Review of operation in accordance with storage permit
- Monitoring and reporting on geologic carbon
- Approval of monitoring/corrective measures plan updates
- Implementation of approved corrective measures
- Periodic adjustment of financial security

The geologic storage operator should regularly report monitoring results and any corrective measures taken to the competent authority. There also needs to be a regular review of the storage permit (after the first 5 years and every ten years thereafter) with the relevant authority.

When further development and drilling activities are undertaken, the risk assessment should be extended and updated accordingly, and data from new wells or development should be used by the operator to verify and update the characterization of the storage complex as well as modeling and risk assessment.

When CO_2 injection into the storage site ceases, the storage site should be closed in accordance with the approved plan. The closure can happen if:

- The total quantity of CO_2 authorized to be geologically stored is reached, or it is deemed unsafe to continue injection
- The geologic storage operator requested site closure (for example, if injection becomes uneconomic)
- A competent authority withdraws the storage permit if the geologic storage operator fails to meet adequate requirements.

The activities at geologic storage site closure include updating the provisional post-closure plan, cessation of injection, plugging and abandoning of selected wells, equipment removal, and on-site inspection. The post-closure monitoring phase starts after well closure. The primary goal in the post-closure monitoring is to ensure that the stored CO_2 is behaving as expected without any detectable leakages and, where relevant, the site reaches specified conditions for the transfer of liabilities to the state. The length of this phase is determined by how long it will take to meet the criteria of evolution towards long term stability of the CO_2 stored in the reservoir. During the post-closure period the geologic storage operator is liable to remedy any leakage or significant irregularities, prior to any transfer of liabilities to the state.

21.2 Calculation guidance and methods for geologic storage pathways

21.2.1 Life cycle GHG emissions accounting methods

This section provides calculation guidance and methods for estimating:

- Captured CO_2 with geologic storage (section 21.2.2)
- Removals with geologic storage (section 21.2.3)
- Carbon losses from enhanced oil recovery (section 21.2.4)
- Fugitive GHG emissions from geologic reservoirs (section 21.2.5)
- Monitoring of carbon stored in geologic reservoirs (section 21.2.6)

This chapter does not include calculation guidance and methods to estimate GHG emissions relating to extraction, production, processing, refrigeration, transportation, distribution, storage, use, end-of-life and other processes attributed to raw materials, capture CO_2 or oil and gas produced from geologic storage pathways. General accounting guidance on estimating such GHG emissions can be found in the *Scope 3 Calculation Guidance*. Additional resources and databases with life cycle GHG emission factors are provided under the calculation tools and third-party life cycle databases on the *GHG Protocol* website. Companies should refer to more detailed sector-specific guidance as needed.

Calculation guidance for estimating land use change, land carbon stock changes and other land management GHG emissions during production of biogenic feedstocks associated with captured biogenic CO_2 stored in geologic reservoirs is provided in chapters 17, 18 and 19. Calculation guidance for estimating GHG emissions from technological CO_2 removal processes is provided in Annex A.

21.2.2 Captured CO_2 with geologic storage

Not all captured CO_2 is stored within geologic reservoirs. Companies should estimate emissions of captured CO_2 following equation 21.1.

Equation 21.1 Annual emissions of captured CO_2

$$E_C = C - C_{GS}$$

E_C	=	Annual emission of captured CO_2 ($t\ CO_2\ yr^{-1}$)
C	=	Annual captured CO_2 ($t\ CO_2\ yr^{-1}$)
C_{GS}	=	Annual captured CO_2 with geologic storage. *See Equation 21.2 ($t\ CO_2\ yr^{-1}$)*

Captured CO_2 with geologic storage should only be reported for the portion of captured CO_2 injected into a geologic reservoir that remains stored. Captured CO_2 with geologic storage can be estimated for a particular reservoir using equation 21.2.

Equation 21.1 **Annual captured CO_2 with geologic storage**

$$C_{GS} = I \times f_{CE} - L - E_F$$

C_{GS}	=	Annual captured CO_2 with geologic storage ($t\ CO_2\ yr^{-1}$)
I	=	Annual CO_2 injected into the geologic reservoir ($t\ CO_2$ injected yr^{-1})
f_{CE}	=	Fraction of CO_2 injected from captured CO_2 ($t\ CO_2$ captured ($t\ CO_2$ injected)$^{-1}$)
L	=	Losses of geologic carbon in the reporting year. *See Section 21.2.4 ($t\ CO_2\ yr^{-1}$)*
E_F	=	Fugitive geologic CO_2 emissions. *See Section 21.2.5 ($t\ CO_2\ yr^{-1}$)*

Note that the annual CO_2 injected into the geologic reservoir, *I*, can come from a variety of sources including: fossil CO_2 from other geologic formations, CO_2 captured from industrial facilities combusting fossil fuels or other materials part of the long term carbon cycle, biogenic CO_2 captured from facilities combusting biogenic feedstocks or direct air captured CO_2.

Where the geologic storage pathway contains enhanced oil recovery, losses of geologic carbon must be included in the estimate following the guidance in section 21.2.4. Fugitive geologic CO_2 emissions should be detected through ongoing monitoring of wells into the geologic reservoir, areas where leakage has been detected or other fugitive GHG emissions, as determined through the geologic storage permitting process and following the guidance in section 21.2.5.

Where data is available, companies should directly track the flow of captured CO_2 from facilities with emission capture to the injection well at a geologic reservoir. The following data should be used to monitor captured CO_2 flows and estimate any fugitive emissions of captured CO_2:

- Volume, mass or flow measurements at the emission capture sites of CO_2 transferred to the transportation and distribution system (e.g., ship, trains, pipeline, barges)
- Volume, mass or flow measurements at each CO_2 exchange within the transportation and distribution system
- Volume, mass or flow measurement of the CO_2 transfer from transportation and distribution system to the geologic reservoir (e.g., for transfer from ships to the injection facilities)
- Where relevant to the transportation and distribution system, analysis of the CO_2 concentration in the gas stream

Based on this data fugitive emissions of captured CO_2 during transportation and distribution can be calculated using level or flow measurements at each loading and offloading points. Any vented volumes and fugitive CO_2 emissions should be accounted for based on the difference between inputs and outputs between each step of the CO_2 transportation and distribution system.

21.2.3 Removals with geologic storage

Removals with geologic storage should only be reported for the portion of CO_2 injected into the reservoir of recent atmospheric origin (i.e., originating from biogenic carbon from lands with stable or increasing carbon stocks or technological CO_2 removal processes) that remains stored. Annual removals with geologic storage for a particular geologic storage reservoir can be estimated using equation 21.3.

Equation 21.3 Annual CO_2 removals with geologic storage

$$R_{GS} = I \times (f_{BR} + f_{TR}) - L - E_F$$

R_{GS}	=	Annual CO_2 removals with geologic storage (t CO_2 removals with geologic storage yr^{-1})
I	=	Annual CO_2 injected into the geologic reservoir (t CO_2 injected yr^{-1})
f_{BR}	=	Fraction of CO_2 injected from capture biogenic CO_2 with removals (t biogenic CO_2 removals (t CO_2 injected)$^{-1}$)
f_{TR}	=	Annual of CO_2 injected from technologically removed CO_2 (t technological CO_2 removals (t CO_2 injected)$^{-1}$)
L	=	Losses of geologic carbon in the reporting year. *See Section 21.2.4 (t CO_2 yr^{-1})*
E_F	=	Fugitive geologic CO_2 emissions. *See Section 21.2.5 (t CO_2 yr^{-1})*

The fraction of CO_2 injected from biogenic removals is estimated based on the share of CO_2 sourced from biogenic CO_2 capture facilities (e.g., bioenergy carbon capture facilities) with biogenic feedstocks sourced from lands with stable or increasing net land carbon stock changes (see chapter 8 and 18 for guidance on estimating land carbon stock changes). The fraction of CO_2 injected from technologically removed CO_2 is estimated based on the amount of CO_2 sourced from technological CO_2 removal facilities (e.g., direct air capture facilities). Annex A contains additional information on accounting for technological CO_2 removals.

Where the geologic storage pathway contains enhanced oil and gas recovery, loss of geologic carbon must be included in the estimate following the guidance in section 21.2.4. Fugitive geologic CO_2 emissions should be detected through ongoing monitoring of wells into the geologic reservoir, areas where leakage has been detected or other fugitive GHG emissions, as determined through the geologic storage permitting process and following the guidance in section 21.2.5.

21.2.4 Carbon losses from enhanced oil and gas recovery

Companies are required to account for any losses of carbon from the geologic reservoir when estimating removals with geologic storage or captured emissions with geologic storage for geologic storage pathways with enhanced oil and gas recovery. Annual losses of carbon from a geologic reservoir can be determined using equation 21.4.

Equation 21.4 Losses of carbon from a geologic reservoir in the reporting year

$$L = P \times 44/12 + V - R$$

L	=	Losses of carbon from the geologic reservoir in the reporting year (t CO_2 yr^{-1})
P	=	Annual carbon produced from the geologic reservoir (t C yr^{-1})
V	=	Annual CO_2 recovered and vented on site (t CO_2 yr^{-1})
R	=	Annual CO_2 recovered and reinjected into the geologic reservoir (t CO_2 yr^{-1})

The annual carbon produced from the geologic reservoir is determined based on the total annual mass of C from any natural gas, oil or other hydrocarbons produced from the well. Geologic storage operators should also report any CO_2 recovered and vented from wells or processing facilities on site. Any CO_2 that is recovered and reinjected into the geologic reservoir can be subtracted from the carbon produced from the well as this does not constitute a loss of carbon leaving the geologic storage system.

21.2.5 Fugitive geologic CO_2 emissions

Fugitive GHG emissions from geologic reservoirs are not expected to occur from appropriately selected and managed geological reservoirs. However, monitoring system must be in place to detect, account for and report potential GHG emissions or reversals. Companies should put in place a comprehensive monitoring program able to detect potential leakage and that can provide calibration parameters for numerical models developed as part of the operations.

Detection of CO_2 leakage and quantification of fugitive geologic CO_2 emissions from leakage can be done by comparing baseline and monitoring data as shown in equations 21.5 and 21.6.

Equation 21.5 Fugitive geologic CO_2 emissions from leakage

$$E_F = C_{measured} - \Delta C_{nat\ measured} - C_{baseline}$$

E_F	=	Fugitive geologic CO_2 emissions (t CO_2 yr^{-1})
$C_{measured}$	=	Annual measured CO_2 at leakage site (t CO_2 yr^{-1})
$\Delta C_{nat\ measured}$	=	Annual natural fluctuation of CO_2 at the site (t CO_2 yr^{-1})
$C_{baseline}$	=	Annual invariant theoretical CO2 baseline (t CO_2 yr^{-1})

If leakage is identified, an enhanced monitoring program should be implemented to quantify and estimate the extent of the leakage to the atmosphere or ocean. The tools deployed will be site specific.

Equation 21.6 Annual measured CO_2 emissions from leakage

$$C_{measured} = C_{flux} \times A$$

$C_{measured}$	=	Annual measured CO_2 (t CO_2 yr^{-1})
C_{flux}	=	CO_2 flux at leakage site (t CO_2 ha^{-1} yr^{-1})
A	=	Estimated area of leakage (ha)

The model used by the reporting company should follow best practices and include all relevant thermal–hydraulic–mechanical–chemical reservoir processes. The aim of the model is to simulate the expected fate of the injected CO_2. History matching should show agreement between the modeling and the monitored behavior (flux based, indirect, remote sensing) of the carbon dioxide plume, and that no leakage is expected. All available evidence should indicate that stored carbon dioxide will be completely isolated from the atmosphere in the short and long term.

Fugitive CO_2 emissions can also occur at injection, production or other wells that penetrate the storage formation. All wells whether they are active or closed should be identified and included in the monitoring plan. Wells should be sampled on regular interval or measured continuously. A flux-based method can be used to quantify the amount of the CO_2 transferred back to the surface. The amount of CO_2 measured must be compared to background value using equation 21.5 to estimate fugitive CO_2 emissions from wells within the geologic reservoir.

Fugitive CO_2 emissions should be accounted for when determining annual captured CO_2 with geologic storage (see section 21.2.2) and removals (see section 21.2.3). Fugitive CO_2 emissions should also be reported in the appropriate scope and any reversals should be accounted for following guidance in chapter 6.

21.2.6 Monitoring stored geologic carbon

Companies should have systems in place of ongoing storage monitoring of the CO_2 stored in the geologic reservoir, in addition to monitoring fugitive CO_2 emissions from geologic reservoirs. This section provides detailed guidance for the following general types of approaches for estimating carbon stored in geologic reservoirs:

1. Flux-based approaches
2. Indirect methods
3. Remote sensing-based approaches
4. Model-based approaches

Flux-based approaches

The most accurate method to determine carbon stock changes is to measure the flow and the concentration of the CO_2 transferred from one carbon pool to another. These provide direct and accurate measurement of the transferred CO_2. The sensors should follow well-established calibration procedures at regular intervals to keep measurement uncertainty low (usually < 5% measurement error).

Indirect methods

Physical or chemical methods can be used to track the fate of the injected CO_2. These may ensure that the trapping mechanism in place are efficient, and the CO_2 remains within the geological formation. These provide indirect indication of unexpected leakage or if CO_2 storage is successful.

Remote sensing-based approaches

Several types of remote sensing data are available to detect land and sea floor management practices and carbon stocks. Remote sensing technology can effectively cover much larger areas in comparison to direct measurement-based methods. It is important to note that background measurements of the CO_2 flux prior to the operation must be undertaken. Local calibration and/or model development is required to derive predictions from the remotely sensed data.

Model-based approaches

The commonly used method for estimating CO_2 storage capacity is reservoir modelling. Model-based approaches use mathematical modelling based on various input variables (e.g., temperature, pressure, rock properties, management practices, etc.) to estimate subsurface behavior of CO_2 in the geologic reservoir. Companies should provide evidence that during operations the model estimates do not deviate from the uncertainty ranges for the predicted subsurface CO_2 behavior defined prior of injection.

The accuracy of models is variable and depends on the robustness of the model, the calibration of the fixed parameters to the application, and the accuracy of the input variables.

For example, if a model is used in new geological settings for which it was not previously calibrated, it may not be reliable. As the CO_2 storage capacity depends on both reservoir properties and migration of the injected CO_2 (e.g., based on number of wells and start of their operation) usually an uncertainty study is performed. The result of such a study gives an uncertainty range of possible outcomes and their probability.

Annexes:
Sector-specific guidance

A

Technological Carbon Dioxide Removals

Annex A: Technological Carbon Dioxide Removals

Guidance

All integrated assessment models that reach the 1.5°C target in the IPCC's Special Report on Global Warming of 1.5°C consider technologies that remove CO_2 from the atmosphere (i.e., technological carbon dioxide removal (TCDR) process).[51] The extent to which the different models apply TCDR processes depends on the speed and extent of emission reductions and reaches values ranging from 100 to 1000 Gt by the end of the century. As a minimum, TCDR and storage pathways are required to balance residual emissions over the long term.

Even integrated assessment models that limit global warming to below 2°C assume TCDR capacities of 2 to 10 Gt per year by 2050, corresponding to 5-25% of the 2010 CO_2 emissions. This means that the fast development of reliable large-scale CDR technologies is vital to achieving the climate target under the Paris Agreement, in addition to using conventional mitigation strategies. There is a broad scientific consensus that a new sector for TCDR is a necessary mitigation strategy to remain within temperature limits set within the Paris Agreement.

This annex applies to companies that operate technological CO_2 removals facilities or are in value chains with technological CO_2 removals. It provides guidance on different technological removals processes, quantification methods, monitoring requirements and data quality when estimating CO_2 removals from TCDR processes such as direct air capture technologies.

Annex overview

Section	Accounting guidance
A.1	Introduction to technological removals
A.2	Quantification
A.3	Monitoring
A.4	Data quality

21.3 A.1 Introduction to technological removals

Direct Air Capture (DAC) technological removals are categorized as processes that capture CO_2 from the atmosphere at atmospheric concentrations and transfer it to a non-atmospheric carbon pool (e.g., product or geologic carbon pools). Conceptually, the capture step is similar to the capture of CO_2 from flue gases or other concentrated sources (CCS), but DAC is part of a removal pathway since it removes CO_2 from the atmosphere while CCS is not.

[51] IPCC, 2018

The DAC process must selectively capture CO_2 molecules, while other constituents of air pass through. However, there are important technological differences compared to capture processes for concentrated sources due to the relatively low concentration of CO_2 in air (about 415 ppm or 0.04% compared to typically 3-20% for concentrated sources). Active materials with a strong affinity for CO_2 are required to bind CO_2 effectively, despite the low concentration.

Two fundamentally different designs for engineered DAC have been developed for commercial applications at this time: absorption and adsorption processes. Both follow a cyclic approach, where the active material is loaded with CO_2 in a first step and regenerated in a second step in which the CO_2 is released:

- **Absorption** processes use strongly alkaline solutions to bind CO_2. In a second step, the resulting CO_2-rich solution is treated to recover the solvent, which can then be reused, and CO_2 is released at high purity.
- **Adsorption** processes use functionalized, solid sorbent materials with high surface area to which the CO_2 binds. In a second step, the sorbent is regenerated and the CO_2 is released at high purity.

Box A.1 Example of direct air captured and rapid carbon mineralization in Iceland

Since 2017, the Swiss company Climeworks is operating the world's first plant that creates carbon dioxide removals through direct air capture of CO_2. The plant is part of the CarbFix2 project which stores the air-captured CO_2 safely and permanently in basalt.

CarbFix2 has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 764760 and is led by Iceland's multi-utility company Reykjavik Energy. The collaborative research project centers around one of the world largest geothermal power plants in Hellisheidi, Iceland, where CO_2 has previously been stored.

Here's how it works:

- The Climeworks DAC module captures CO_2 from ambient air
- The CO_2 binds to the filter
- Once the filter is saturated with CO_2, it is heated by low-grade waste heat from the geothermal plant
- The CO_2 is released and bound to water
- The carbonated water is injected into the underground
- It then reacts with the basaltic bedrock, forming solid minerals
- A permanent, safe and irreversible storage solution is created

The CarbFix2 project imitates natural processes but speeds them up rapidly. The potential of scaling up with this effective CO_2 storage is enormous: it unlocks possibilities in Iceland and numerous other regions in the world where there is a similar geological foundation of basalt. In 2020, Climeworks is scheduled to increase the removal capacity in Iceland.

Enhanced weathering (EW) is another type of technological removal which follows a similar process using materials that show a strong affinity for CO_2 capture (e.g., olivine or basalt dust). These materials react with CO_2 when exposed to air with atmospheric carbon concentrations to form carbonate minerals. Subsequent recovery of the carbon from the material is not foreseen. The process is similar to DAC adsorption but EW involves passive treatment that waits for the reactions to naturally occur over a longer time scale and only once, rather than applying active engineering.

Accounting for technological CO_2 removals

As demonstrated in table A.1, TCDR process can be associated with a company's operations (scope 1) or value chain (scope 3).

Table A.1 How to account for net vs. gross technological removals in the scopes

	Net technological CO_2 removals (stock-change accounting categories)	**Gross technological CO_2 removals (flow accounting categories)**
Scope 1 technological removals	Scope 1 net technological CO_2 removals are net increases to storage in geologic carbon pools from technological CO_2 sinks where the reporting company owns or controls both the technological removal facility(ies) and the associated geologic carbon storage pool(s) Companies should follow the guidance in chapter 10 to account for and report scope 1 *Net technological removals with geologic storage*. Technological CO_2 removals stored in carbon pools that are subsequently transferred to other parties are not accounted for in scope 1 and may be accounted for in scope 3 following the guidance below.	Direct *Gross technological CO_2 removals* are the transfer of atmospheric CO_2 via technological sinks owned by the reporting to storage in TCDR-based products or geologic carbon pools. Companies that own or control technological sinks (e.g., a DAC facility) may account for the annual gross technological CO_2 removals from their operations and report them separately from scope 1 removals as gross technological CO_2 removals by scope.[52]
Scope 3 technological removals	Scope 3 net technological CO_2 removals are net increases to storage in product or geologic carbon stocks from carbon derived from technological CO_2 sinks in the value chain of the reporting company. Companies should follow the accounting guidance in chapter 9 for scope 3 *Net technological removals with product storage* or chapter 10 for scope 3 *Net technological removals with geologic storage*.	Indirect *Gross technological CO_2 removals* are the transfer of atmospheric CO_2 via technological sinks to storage in TCDR-based products or geologic carbon pools in the value chain of the reporting company. Companies that do not own or control technological sinks but are in value chains with technological removals (e.g., a geologic storage operator acquiring direct air captured CO_2 or a company manufacturing direct air captured CO_2-based products) may account for the annual gross technological CO_2 removals from facilities in their value chain and report them separately from scope 3 removals as gross technological CO_2 removals by scope.[2]

Investments in technological removals

Companies may also account for scope 1 or scope 3 removals from investments in DAC companies/facilities depending on the consolidation method selected for defining the organizational boundary and share in ownership of the company/facility (see chapter 5 for details), subject to the requirements in chapter 6.

[52] Subject to open question #1 on reporting gross emissions and gross removals.

If multiple companies have ownership or control in the DAC company or facility, they should specify in contractual agreements which entity (or entities) account for scope 1 removals such that total scope 1 removals are not overreported across companies (see chapter 10).

Companies should refer to the *Scope 3 Standard* guidance on category 15, investments (pages 51-54) on how to account for equity investments, debt investments, project finance, and other types of investments, and the Partnership for Carbon Accounting Financial sector guidance.[53]

Credited technological removals

Credited technological removals refer to when a company purchases GHG credits associated with technological removals and storage. Companies that do not have the opportunity to own or control technological removal facilities or include them in their value chain, may opt to buy credited removals associated with technological removals (e.g., GHG credits from direct air capture and geological storage projects). Credits purchased from technological removal processes must comply with the requirements and guidance outlined in chapter 13.

21.4 A.2 Quantification

The calculation procedure for the CO_2 capture process reflects the boundary of the capture site, encompassing the capture facility, as well as auxiliary equipment associated with the CO_2 capture and compression systems and purchased electricity or thermal energy. If the project is part of an industrial complex (e.g., for heat recovery) with many processes unaffected by or independent of the CO_2 capture activities, only those processes directly impacted by the CO_2 capture process are included in the quantification assessment. The boundary of the capture site extends to the point at which the GHG is transferred to the operator of the subsequent pool (e.g., geologic storage operator or CO_2-base product manufacturer).

Companies should follow the guidance in the *Corporate Standard and Scope 2 Guidance and Corporate Value Chain (Scope 3) Standard* to determine where emissions should be reported depending on the reporting company's location in the value chain. Equation A.1 outlines the methods for calculating GHG emissions from the capture facilities.

Equation A.1 GHG emissions from capture and compression facilities

$$E_{Capture} = E_{Primary\ process} + E_{Combustion} + E_{Energy}$$

$E_{Capture}$	=	Emissions from CO_2 capture and compression (t CO_2-eq yr^{-1})
$E_{Primary\ process}$	=	Emissions from the primary process that have not been captured by the process, including emissions from venting of CO_2 during capture and compression and emissions from fugitive release of CO_2 during capture and compression (t CO_2-eq yr^{-1})
$E_{Combustion}$	=	Emissions from onsite use of fossil fuels to operate support equipment for the CO_2 capture and compression facilities (t CO_2-eq yr^{-1})
E_{Energy}	=	Emissions from purchased electricity and thermal energy used to operate the CO_2 capture and compression system (t CO_2-eq yr^{-1})

[53] Available at https://ghgprotocol.org/global-ghg-accounting-and-reporting-standard-financial-industry

Vented and fugitive emissions from capturing and compressing CO_2, as represented by the parameter $E_{primary\ process}$ in equation A.1, include both intentional and unintentional releases. CO_2 may be vented during normal operation, process upsets or shutdowns. Fugitive emissions may arise from leakage of CO_2 from equipment such as flanges, valves and flow meters.

Equation A.2 outlines how to quantify the amount of gross technological CO_2 removals associated with CO_2 captured by the DAC facility.

Equation A.2 Gross technological CO_2 removals

$$T_{CO_2} = V_{CO_2} \times C_{CO_2} \times P_{CO_2}$$

T_{CO_2}	=	CO_2 captured and transferred to the CO_2 downstream applications, metered at the point of transfer to the downstream application (t CO_2 yr^{-1})
V_{CO_2}	=	Total volume of gas that has been captured and input into the downstream application, metered at the point of transfer with the downstream application (m^3 CO_2 yr^{-1})
C_{CO_2}	=	Concentration of CO_2 in the gas stream measured at the input to the downstream application at standard conditions (% volume)
P_{CO_2}	=	Density of CO_2 at standard conditions (0.001977 t m^{-3})

21.5 A.3 Monitoring

Monitoring requirements include measurements of relevant parameters to account for all supplemental energy inputs (e.g., fossil fuels and electricity) required for the operation of the DAC facility. Data capture must be sufficient to ensure that the quantification and documentation is replicable and verifiable. The following guidance should be followed when monitoring CO_2 removals from DAC facilities:

- Monitoring should include direct measurements of relevant parameters to account for the flow rate of transferred fluids, the concentration of the fluid stream, and the energy inputs required for operation.
- DAC project monitoring techniques must use calibrated metering equipment such as fluid flow meters, utility meters (gas/electricity) and fluid chemistry analyzers.
- Meters must be maintained to operate consistently with manufacturer specifications and calibrated at regular intervals according to these specifications and industry standards.
- Flow meters must be located such that accurate measurements can be collected for accounting purposes. Where possible, flow meters should be placed immediately ahead of the downstream application, such that they account for all capture, compression, and fugitive losses or venting.
- Flow rate data must be used to determine the cumulative volume of CO_2 captured.
- The DAC project operator must sample and analyze the CO_2 stream at a frequency sufficient to yield data representative of the chemical and physical characteristics of the captured gas. Fluid samples must be collected from a point such that the sample is representative of the composition of the gas. Project operators must provide a demonstration of the suitability of the sample point, along with any calculations required for complex systems.
- The fluid composition must be metered downstream of the capture and processing equipment, and volume measured upstream, prior to any mixing of new or recycled CO_2.

21.6 A.4 Data quality

DAC project operators should use primary data measured at the facility to the largest extent possible. The use of secondary data is restricted to calculations of the GHG emissions associated with the construction of DAC plants. In this case, data from peer reviewed life cycle assessment literature is used to inform a conservative estimate.

B

Biomethane

Annex B: Biomethane

Guidance

This annex provides guidance on accounting for biogas or biomethane (also known as renewable natural gas or RNG) based on the current accounting approach under the GHG Protocol Corporate Standard *and* Scope 3 Standard*. This approach uses an average data approach to account for scope 1 and scope 3 emissions.*

The GHG Protocol Scope 2 Guidance *includes a location-based method and market-based method for purchased electricity. Box B.1 provides information on a process to determine the potential suitability of market-based accounting approaches beyond scope 2.*

Sections in this chapter

Section	Description
B.1	Accounting for biomethane emissions in a GHG inventory
B.2	Accounting for pipeline-delivered gas
B.3	Accounting for emissions impacts relative to counterfactual scenarios

21.7 B.1 Accounting for biomethane emissions in a GHG inventory

Biomethane is a form of biogenic gas that has been treated to be used interchangeably with fossil-derived natural gas. Biomethane can be produced from biogas captured from degradation within a variety of systems, including manure lagoons, landfills, anaerobic digesters, or wastewater. Each pathway has unique lifecycle emissions, depending on the specific source and lifecycle of the fuel. Lifecycle emissions sources can include upstream land impacts, processing, transportation and distribution, and combustion.

Using an inventory accounting approach to account for biomethane emissions

Companies in the biomethane value chain should account for the life cycle emissions from biomethane using an inventory approach following the other chapters in this Guidance. Companies calculate and report biogenic net emissions using stock-change accounting in scope 1, scope 2, and scope 3, and separately report *Gross biogenic product CO_2 emissions* using flow-based accounting methods. Chapter 4 provides information on stock-change and flow-based accounting, while chapter 5 (including table 5.8) details the accounting categories to include in the inventory boundary.

Companies that purchase and consume (combust) bioenergy (biomass, biofuels, or biogas) account for and report:

- **Gross biogenic product CO_2 emissions** from stationary or mobile combustion of bioenergy, using CO_2 combustion emission factors by fuel/gas type. These emissions are quantified using emission factors that reflect the CO_2 emissions released to the atmosphere at combustion, by type of biomass/biofuel/biogas.[54] These emissions are separately reported from scope 1, scope 2, and scope 3 emissions as gross emissions, not aggregated with net emissions, and are organized by scope category to differentiate direct and indirect gross emissions (see table 5.8).

- **Scope 1, scope 2, or scope 3 methane (CH_4) and nitrous oxide (N_2O) emissions** from stationary or mobile combustion of bioenergy (using CH_4 and N_2O combustion emission factors by fuel/gas type)
- **Scope 3, category 3 upstream emissions from purchased bioenergy** (extraction, production, and transportation of bioenergy consumed by the reporting company). This includes all cradle-to-gate emissions of purchased bioenergy from raw material extraction up to the point of (but excluding) combustion, including:
    - *Land use change emissions* (see chapter 7 and 17),
    - *Land management net CO_2 emissions* (chapter 8 and 18),
    - *Land management non-CO_2 emissions* (chapter 8 and 19), and
    - emissions from processing, transportation, and all other upstream impacts
- **Any other scope 1, scope 2, or scope 3 emissions**, if applicable
- **Optionally, and if applicable, removals stored in land or geologic carbon pools**, using stock-change accounting methods (further described in chapter 6)
- **One or more land tracking metrics** (*Indirect land use change emissions*, *Carbon opportunity costs*, *Land occupation*), reported separately from emissions and removals

Allocating for waste

The accounting approach above depends on how emissions and removals are allocated to waste streams. Companies should refer to chapter 16, section 16.5.2 for guidance on allocating emissions and removals to waste.

21.8 B.2 Accounting for pipeline-delivered gas

Energy users typically receive gas from a common carrier pipeline rather than a dedicated pipeline. Common carrier pipelines can contain a mix of biogenic and fossil gas and do not differentiate or track unique molecules of gas from the point of injection to the point of consumption. In contrast, dedicated pipelines allow for differentiation by type and origin of gas.

Under the GHG Protocol *Corporate Standard* and *Scope 3 Standard*, companies account for emissions from common pools or distribution systems using an average data method. For example, when consuming gasoline from a common pool that includes 85% gasoline and 15% ethanol, companies account for 85% of the fuel using a gasoline emission factor and report this in scope 1, and account for 15% of the fuel using an ethanol emission factor and report this as biogenic CO_2 emissions outside of the scopes.

For natural gas that is sourced from a common pipeline, companies should determine what percentage of the gas is of fossil or biogenic origin. Given the inability to trace individual molecules through a common pipeline, companies should use grid-averages, where they exist, to determine the percentage of fossil and biogenic natural gas delivered into the pipeline. Companies should report each portion separately (fossil and biogenic), following the requirements for accounting for and reporting fossil and biogenic emissions.

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[54] Emission factors can be found in the IPCC *Emission Factor Database* (https://www.ipcc-nggip.iges.or.jp/EFDB/main.php), IPCC *Guidelines for National Greenhouse Gas Inventories*, (https://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html), GHG Protocol website (https://ghgprotocol.org/calculation-tools), life cycle inventory databases, and other sources in the List of land sector calculation tools and resources available at https://ghgprotocol.org/land-sector-and-removals-guidance.

In the absence of data on the average grid mix, companies should assume that all pipeline natural gas is of fossil origin. If biogenic gas is delivered directly to a company (e.g., via vehicle-based delivery or direct pipeline), the company should use the specific emission factors (combustion or life cycle emission factors, as applicable) associated with the biogenic gas.

Under the *Corporate Standard*, scope 1 emissions are direct emissions occurring from sources owned or controlled by the reporting company and are required to be reported independent of any trades or purchases of certificates or credits. Biomethane certificates or credits cannot be used to adjust scope 1 emissions resulting from the combustion of gas (in company owned/controlled sources) delivered via a common carrier pipeline. Companies may report purchases of certificates or credits separately from the scopes in a GHG inventory report.

Box B.1 Note on market-based accounting

The *Scope 2 Guidance* introduced a methodology for accounting for scope 2 emissions from purchased electricity, steam, heating, or cooling using two methods:

- The location-based method, which reflects the average emissions intensity of grids on which energy consumption occurs (using mostly grid-average emission factor data).
- The market-based method, which reflects emissions from electricity that companies have purposefully chosen (or their lack of choice). It derives emission factors from contractual instruments, which include any type of contract between two parties for the sale and purchase of energy bundled with attributes about the energy generation, or for unbundled attribute claims.

Companies with any operations in markets providing product or supplier-specific data in the form of contractual instruments are required to report scope 2 emissions according to both the location-based method and the market-based method (i.e., "dual reporting"). The *Scope 2 Guidance* defines additional requirements for market-based accounting of purchased electricity such as meeting several quality criteria for contractual instruments and the use of residual emission factors.

Additional market-based accounting approaches have been proposed for a variety of other commodities, markets, and end-uses since the introduction of the *Scope 2 Guidance*. These proposals would seek to expand market-based accounting to scope 1 and/or scope 3. At the same time, there has been mixed feedback on the use of the market-based method in scope 2, including some criticisms about its efficacy and appropriateness.

The GHG Protocol is undertaking a process to determine the need and scope for additional guidance building on the existing set of corporate GHG accounting and reporting standards for scope 1, scope 2, and scope 3 emissions. As part of this process, the GHG Protocol plans to holistically examine the appropriateness for market-based accounting across sectors, end-uses, and scopes. This process would seek to explore both whether market-based accounting is appropriate within scope 1 and/or scope 3 and also whether the accounting approach for scope 2 (e.g., dual reporting using location-based and market-based methods, market instrument quality criteria, etc.) would need to be applied, amended, or expanded if applied outside of scope 2. The process to develop new guidance will begin in 2023. Based on the final outputs of this process, the contents of this annex may be amended.

21.9 B.3 Accounting for emissions impacts relative to counterfactual scenarios

Biomethane can have positive climate impacts, primarily through the avoidance of methane emissions at the source (e.g., manure lagoons, landfills, etc.). The avoidance or displacement of emissions that would have otherwise occurred is classified as an avoided emission and is calculated using a project or intervention accounting method (quantified relative to a counterfactual baseline scenario), rather than an inventory accounting methods. Companies may quantify and report avoided emissions impacts separately from the scopes using project or intervention accounting methods.

Refer to chapter 11 for guidance on quantifying GHG impacts of actions using project or intervention accounting methods, as well as guidance on using inventory methods and project or intervention methods in combination to inform decision making.

For additional guidance on avoided emissions, see:

- GHG Protocol, *Scope 3 Standard*, section 9.5, including box 9.4.[55] The *Scope 3 Standard* states that "Accounting for avoided emissions that occur outside of a company's scope 1, scope 2, and scope 3 inventories requires a project accounting methodology. Any estimates of avoided emissions must be reported separately from a company's scope 1, scope 2, and scope 3 emissions, rather than included or deducted from the scope 3 inventory."
- Russell, 2018. "Estimating and Reporting the Comparative Emissions Impacts of Products"[56]
- GHG Protocol *Project Protocol* (for quantifying GHG impacts of project-scale actions)[57]
- GHG Protocol *Policy and Action Standard* (for quantifying GHG impacts of actions at larger scales)[58]

Box B.2 Relationship with carbon intensity metric

Some programs for evaluating, verifying, and regulating the carbon content of fuels use carbon intensity (CI) as a metric (or "score") for evaluating the climate impacts of fuels such as biogas, biomethane, and other fuels.

Carbon intensity is a measure of life cycle emissions (direct and indirect) associated with the use of a fuel. The metric is often presented in comparison to another fuel or scenario using elements of project or intervention accounting (e.g., to quantify avoided impacts).

CI should not be used as a replacement for an emission factor in inventory accounting because it:

- aggregates all life cycle impacts into a single number, rather than separately accounting for emissions by scope and category, and
- includes elements of project or intervention accounting methods, such as including avoided impacts relative to counterfactual baseline scenarios.

[55] Available at https://ghgprotocol.org/standards/scope-3-standard

[56] Available at https://ghgprotocol.org/estimating-and-reporting-avoided-emissions

[57] Available at https://ghgprotocol.org/standards/project-protocol

[58] Available at https://ghgprotocol.org/policy-and-action-standard

Glossary

Glossary

Aboveground biomass carbon pool	Carbon in terrestrial living woody or herbaceous vegetation 2 mm in size or greater.
Activity-based calculation	Calculation that uses activity data and emissions or carbon stock change factors.
Allocation	The process of partitioning GHG emissions and removals from a single process or other system among its various outputs.
Aquaculture	Breeding and rearing aquatic animals (fish and shellfish) or the cultivation of aquatic plants.
Assurance	The level of confidence that the inventory and report are complete, accurate, consistent, transparent, relevant, and without material misstatements.
Assurer	A competent individual or body who is conducting the assurance process, whether internally within the company or externally.
Attributable processes	Individual interconnected processes in a product life cycle (from raw material acquisition or generation of natural resources to end of life), including service, material, and energy flows that become the product, make the product, and carry the product through its life cycle.
Audit trail	Well organized and transparent historical records documenting how the GHG inventory was compiled.
Avoided emissions	GHG emissions that are prevented as a result of a company's action(s), compared to alternative scenarios without the action(s).
Avoided removals	CO_2 removals that are prevented as a result of a company's action(s), compared to alternative scenarios without the action(s).
Base year	A historic datum (a specific year or an average over multiple years) against which a company's emissions are tracked over time.
Base year or base period emissions	GHG emissions in the base year or base period.
Base year or base period recalculation	Recalculation of emissions and removals (if applicable) in the base year or base period to reflect a change in the structure of the company, or to reflect a change in the accounting methodology used. This ensures data consistency over time, i.e., comparisons of like with like over time.

Belowground biomass carbon pool	Carbon in terrestrial live roots 2 mm in size or greater.
Bioenergy	Any fuel produced by biological processes of living organisms, including organic non-fossil material of biological origin (e.g., plant material), biofuels (e.g., liquid fuels produced from biomass feedstocks), biogenic gas (e.g., landfill gas), and biogenic waste (e.g., municipal solid waste from biogenic sources).
Biofuel	Fuel made from plant material, e.g., wood, straw and ethanol from plant matter.
Biogas	Methane that is produced from a biomass resource, such as animal waste, agricultural waste, landfill gas, municipal waste, or digester gas.
Biogenic carbon	Carbon derived from living organisms or biological processes, but not fossilized materials or from fossil sources.
Biogenic carbon cycle	Carbon cycle pathway that includes biogenic CO_2 removals, transfers of biogenic carbon between carbon pools, and biogenic CO_2 emissions.
Biogenic CO_2 emissions	CO_2 emissions resulting from the combustion, biodegradation or other losses from biogenic carbon pools to the atmosphere.
Biogenic CO_2 removals	CO_2 removals resulting from atmospheric CO_2 transferred via biological sinks to storage in biogenic carbon pools.
Biogenic product carbon pool	Carbon in products or materials derived from living organisms or biological processes, but are not fossilized or from fossil sources.
Biogenic sinks	Biological processes, primarily photosynthesis, that remove CO_2 from the atmosphere.
Biomass carbon pool	Carbon in terrestrial living organisms 2 mm in size or greater. Includes aboveground and belowground biomass carbon pools.
Biomethane	A form of biogenic gas that has been treated to be used interchangeably with fossil-derived natural gas.
Biophysical model	A simulation of a biological system that uses mathematics to estimate or predict changes to the physical properties of that system.
Book and claim	Chain of custody model in which the administrative record flow is not necessarily connected to the physical flow of material or product throughout the supply chain.

Capital lease A lease which transfers substantially all the risks and rewards of ownership to the lessee and is accounted for as an asset on the balance sheet of the lessee. Also known as a Financial or Finance Lease. Leases other than Capital/Financial/Finance leases are Operating leases. Consult an accountant for further detail as definitions of lease types differ between various accepted financial standards.

Carbon opportunity costs (COC) Emissions from total historical carbon loss from plants and soils on lands productively used. This quantity also represents the amount of carbon that could be stored if land in production were allowed to return to native vegetation.

Carbon stock The mass of carbon contained in a carbon pool at a given time. For example, tonnes of biomass carbon on forest lands or tonnes of carbon in building materials.

Carbon stock change The difference in carbon stocks between two points in time.

Carbon storage The process of maintaining carbon dioxide or carbon in a pool for a period of time.

Compensation target Target for achieving mitigation external to the target boundary through purchasing and retiring GHG credits (also called offsets or carbon credits) to compensate for annual or cumulative unabated emissions in the target boundary, if allowed under the relevant target setting program or target setting policy.

Contribution or financing target Target for contributing to financing GHG mitigation outside the company's target boundary, through financing or purchasing and retiring GHG credits applied against contribution targets (without using GHG credits as offsets or compensation).

Control The ability of a company to direct the policies of another operation. More specifically, it is defined as either operational control (the organization or one of its subsidiaries has the full authority to introduce and implement its operating policies at the operation) or financial control (the organization has the ability to direct the financial and operating policies of the operation with a view to gaining economic benefits from its activities).

Controlled blending Chain of custody model in which materials or products with a set of specified characteristics are mixed according to certain criteria with materials or products without that set of characteristics resulting in a known proportion of the specified characteristics in the final output.

Co-product One of multiple products produced by a process or system that has a market value.

Cradle-to-gate emissions	All emissions that occur in the life cycle of purchased products, up to the point of receipt by the reporting company (excluding emissions from sources that are owned or controlled by the reporting company).
Cradle-to-grave emissions	All emissions in a product's life cycle, from material acquisition through to end-of-life.
Dead organic matter (DOM) carbon pool	Carbon in non-living organisms or other non-fossil organic compounds 2 mm in size or greater. Includes dead wood and litter carbon pools.
Deadwood carbon pool	Carbon in non-living woody biomass not contained in litter carbon pools that are 10 mm in size or greater.
Direct emissions	Emissions from sources that are owned or controlled by the reporting company.
Direct land use change (dLUC) emissions	Emissions (primarily from carbon stock losses) due to recent (previous 20 years or more) land conversion directly on the area of land that a company owns/controls or on specific lands in the company's value chain.
Direct measurement	Quantification of GHG emissions or removals, or associated carbon stock changes, using direct monitoring of GHG fluxes, mass balance or stoichiometry.
Econometric model	Application of statistical methods to estimate economic relationships and predict changes to economic variables in a system.
Emission	The release of a greenhouse gas into the atmosphere.
Emissions and removals adjusted for sold credits	Scope 1, scope 2 and scope 3 emission values and scope 1 and scope 3 removal values that are adjusted for GHG credits issued or generated within the inventory boundary.
Enteric fermentation	Fermentation that takes place in the digestive systems of animals.
Equity share	The equity share reflects economic interest, which is the extent of rights a company has to the risks and rewards flowing from an operation or land. Typically, the share of economic risks and rewards in an operation is aligned with the company's percentage ownership of that operation or land, and equity share will normally be the same as the ownership percentage.
Final product	Goods and services that are consumed by the end user in their current form, without further processing, transformation, or inclusion in another product. Final products include not only products consumed by end consumers, but also products consumed by businesses in the current form (e.g., capital goods) and products sold to retailers for resale to end consumers (e.g., consumer products).

Finance lease	A lease which transfers substantially all the risks and rewards of ownership to the lessee and is accounted for as an asset on the balance sheet of the lessee. Also known as a Capital or Financial Lease. Leases other than Capital/Financial/Finance leases are Operating leases. Consult an accountant for further detail as definitions of lease types differ between various accepted accounting principles.
First-party assurance	Person(s) from within the reporting company but independent of the GHG inventory process conducts internal assurance. (Also called "self-" or "internal-assurance.")
Flow accounting	Accounting methods that estimate the gross fluxes of carbon to and from the atmosphere based on the flows of carbon from the atmosphere to the system (i.e., gross removals) and flows of carbon out of the system to the atmosphere (i.e., gross emissions).
Freshwater-based carbon pool	Carbon in freshwater rivers, lakes, reservoirs, or other inland freshwater bodies in organic or inorganic carbon pools.
Fugitive emissions	Emissions that are not physically controlled but result from the intentional or unintentional releases of GHGs.
Geologic carbon pool	Carbon in geologic formations or inorganic minerals that are not used as products.
Geologic storage pathway	The consecutive and interlinked stages associated with the acquisition and storage of carbon in geologic reservoirs.
GHG capture	Collection of a greenhouse gas from a source for storage within a pool.
GHG credit	A convertible and transferable instrument usually bestowed by a GHG program.
GHG flux	The transfer of greenhouse gases or their constituent elements between pools, expressed as an amount over a given time. Also referred to as flow.
GHG program	A generic term used to refer to any voluntary or mandatory international, national, sub-national, government or non-governmental authority that registers, certifies, or regulates GHG emissions or removals outside the company.
GHG project	A specific project or activity designed to achieve GHG emission reductions, storage of carbon, or enhancement of GHG removals from the atmosphere. GHG projects may be stand-alone projects, or specific activities or elements within a larger non-GHG related project.

Gross biogenic land CO_2 emissions	Gross CO_2 emissions from combustion, biodegradation or other losses from land-based carbon pools.
Gross biogenic land CO_2 removals	Gross CO_2 removals from atmospheric CO_2 transferred via biogenic sinks to land-based carbon pools.
Gross biogenic product CO_2 emissions	Gross CO_2 emissions from combustion, biodegradation or other losses from biogenic product carbon pools.
Gross biogenic removal	Transfer by biological sink processes, primarily photosynthesis, of CO_2 from the atmosphere to biogenic carbon pools.
Gross CO_2 emissions from geologic storage	Gross CO_2 emissions from the fugitive losses of CO_2 stored in geologic carbon pools.
Gross emissions	The one directional release of greenhouse gases into the atmosphere.
Gross flux	A one directional greenhouse gas flux that occurs from one pool to another over a defined period of time.
Gross removals	The one directional transfer of greenhouse gases from the atmosphere to storage within a pool.
Gross TCDR-based product CO_2 emissions	Gross CO_2 emissions resulting from the combustion, degradation or other losses from TCDR-based product carbon pools.
Gross technological CO_2 removals	Gross CO_2 removals from atmospheric CO_2 transferred via technological sinks to product or geologic carbon pools.
Identity preserved	Chain of custody model in which the materials or products originate from a single source and their specified characteristics are maintained throughout the supply chain.
Indirect emissions	Emissions that are a consequence of the activities of the reporting company, but occur at sources owned or controlled by another company.
Indirect land use change (iLUC) emissions	Emissions (primarily from carbon stock losses) due to land conversion on lands not owned or controlled by the company, or in its value chain, induced by change in demand for (or supply of) products produced or sourced by the company.
Inset credit	Quantified mitigation outcomes of projects or broader interventions which are credited for GHG claims to be transferred between entities, and which are generated from projects or interventions that reduce emissions or increase removals inside the reporting company's value chain. Credited GHG reductions or removal enhancements are quantified using project or intervention accounting methods, which quantify systemwide GHG impacts relative to a counterfactual baseline scenario or performance benchmark that represent the conditions

most likely to occur in the absence of the mitigation project that generates the credit.

Intermediate product	Goods that are inputs to the production of other goods or services that require further processing, transformation, or inclusion in another product before use by the end consumer. Intermediate products are not consumed by the end user in their current form.
Intervention accounting	Accounting method that quantifies systemwide impacts of a specific action or intervention on GHG emissions and removals relative to a counterfactual baseline scenario that represent the conditions most likely to occur in the absence of the action or intervention.
Inventory accounting	Accounting for GHG emissions and removals over time within a defined inventory boundary relative to a historical base year.
Inventory boundary	An imaginary line that encompasses the direct and indirect emissions that are included in the inventory. It results from the chosen organizational and operational boundaries.
Inventory emissions and removals	Scope 1, scope 2 and scope 3 emissions and scope 1 and scope 3 removals, independent of GHG credit purchases/sales.
Land emissions	Land use change emissions, land management net CO_2 emissions, and land management non-CO_2 emissions.
Land management net CO_2 emissions (biogenic)	Biogenic CO_2 emissions resulting from net carbon stock losses due to ongoing land management practices.
Land management net removals	Net increases to storage in land carbon pools due to ongoing land management practices.
Land management non-CO_2 emissions	CH_4, N_2O and non-biogenic CO_2 emissions due to ongoing land management practices.
Land management unit	A predefined, spatially explicit area of a given land use, managed according to a clear set of objectives according to a single land management plan.
Land occupation	The amount of land occupied for a certain time to produce a product.
Land tracking	A category of metrics to account for and report land use and land use change impacts beyond a company's GHG inventory boundary, helping to ensure that a company's land-use and sourcing decisions lead to meaningful system-wide GHG reductions. These metrics include indirect land use change emissions, carbon opportunity costs, and land occupation.

Land use change	A transition from one land use category to another, such as from forest to grassland or cropland.
Land use change emissions	Emissions (primarily from carbon stock losses) due to land conversion.
Land-based carbon pool	The carbon in terrestrial biomass, dead organic matter and soil carbon pools.
Land carbon stock change	The annual change (occurring in the reporting year) in the total land carbon stock.
Leakage (displacement)	An increase in emissions or a decrease in removals outside a company's inventory boundary resulting from the company's actions to reduce emissions or increase removals within its inventory boundary.
Leakage (geologic)	Fugitive GHG emissions due to losses of injected CO_2 from the geologic formation.
Leased asset	Any asset that is leased (e.g., facilities, vehicles, etc.).
Lessee	An entity that has the right to use an asset through a contract with the owner of the asset (i.e., the lessor).
Lessor	An entity that owns an asset and leases it to a third party (i.e., the lessee).
Level of assurance	Refers to the degree of confidence stakeholders can have over the information in the inventory report.
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to end of life.
Life cycle assessment	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.
Litter carbon pool	Carbon in non-living vegetation or other non-fossil organic compounds that are between 2-10 mm in size.
Market-mediated effects	Changes in resource use and/or environmental impacts as a result of changes in demand for a good or service and changes in price of that good or service.
Mass balance	Chain of custody model in which materials or products with a set of specified characteristics are mixed according to defined criteria with materials or products without that set of characteristics.

Material misstatement	Individual or aggregate errors, omissions and misrepresentations that significantly impact the GHG inventory results and could influence a user's decisions.
Materiality	Concept that individual or the aggregation of errors, omissions and misrepresentations could affect the GHG inventory and could influence the intended users' decisions.
Mineral soil organic carbon pool	Carbon in soil organic matter that is smaller than 2 mm in size in soil types that are not classified as organic soils.
Mobile combustion	Burning of fuels by transportation devices such as cars, trucks, trains, airplanes, ships etc.
Model-based calculation	Methods that use mathematical modeling techniques to estimate emissions, removals, or carbon stock changes using input variable and fixed parameters calibrated to the specific model applications.
Net CO_2 emissions from biogenic product storage	CO_2 emissions resulting from net carbon stock decreases in biogenic product carbon pools.
Net CO_2 emissions from geologic storage	CO_2 emissions resulting from net carbon stock decreases in geologic carbon pools.
Net CO_2 emissions from TCDR-based product storage	CO_2 emissions resulting from net carbon stock decreases in TCDR-based product carbon pools.
Net flux	The difference between greenhouse gas emissions to and removals from the atmosphere to a given carbon pool or set of carbon pools over a defined period of time. Net GHG emissions are expressed as positive values and net GHG removals are expressed as negative values.
Net removals with geologic storage	Net CO_2 removals resulting from annual net increases to carbon stored in geologic carbon pools from carbon derived from biogenic or technological CO_2 sinks.
Net removals with product storage	Net CO_2 removals resulting from annual net increases to carbon stored in product carbon pools from carbon derived from biogenic or technological CO_2 sinks.
Net-negative emissions	Removals exceed emissions within the target boundary, and emissions are reduced in line with 1.5°C pathways
Net-zero emissions	Emissions equal removals within the target boundary, and emissions are reduced in line with 1.5°C pathways and removals are used to neutralize residual emissions.

Non-land emissions	All emissions other than land emissions (land use change emissions, land management net CO_2 emissions, and land management non-CO_2 emissions), such as stationary combustion, mobile combustion, fugitive, and process emissions.
Ocean-based carbon pool	Carbon in marine organic or inorganic carbon pools.
Offset credit	Quantified mitigation outcomes of projects or broader interventions which are credited for GHG claims to be transferred between entities, and which are generated from projects or interventions that reduce emissions or increase removals outside the reporting company's value chain. Credited GHG reductions or removal enhancements are quantified using project or intervention accounting methods, which quantify systemwide GHG impacts relative to a counterfactual baseline scenario or performance benchmark that represent the conditions most likely to occur in the absence of the mitigation project that generates the credit.
Operating lease	A lease which does not transfer the risks and rewards of ownership to the lessee and is not recorded as an asset in the balance sheet of the lessee. Leases other than Operating leases are Capital/Financial/Finance leases. Consult an accountant for further detail as definitions of lease types differ between various accepted financial standards.
Operation	A generic term used to denote any kind of business, irrespective of its organizational, governance, or legal structures. An operation can be a facility, subsidiary, affiliated company or other form of joint venture.
Operational boundaries	The boundaries that determine the direct and indirect emissions, removals, and other accounting categories associated with operations owned or controlled by the reporting company.
Organic soil organic carbon pool	Carbon in soil organic matter that is smaller than 2 mm in size in organic soils that have an organic horizon greater than or equal to 10 cm in thickness and have greater that 12 to 20 percent organic carbon by weight depending on soil texture and subjectivity to water saturation.
Pool	A physical reservoir or medium where a GHG or its constituent elements are stored.
Primary data	Data from specific activities within a company's value chain.
Process emissions	Emissions generated from manufacturing processes, other than stationary combustion, such as the CO_2 that is arises from the breakdown of calcium carbonate ($CaCO_3$) during cement manufacture.

Product carbon pool	Carbon in products or materials not included within land-based or geologic carbon pools. Includes biogenic, fossil and technological carbon dioxide removal (TCDR)-based products.
Product carbon stock change	The annual change (occurring in the reporting year) in the total biogenic or TCDR-based carbon stock contained in products sold by the reporting company in the reporting year or in past years.
Product removal and storage pathway	The consecutive and interlinked stages of carbon storage in products, either through photosynthesis from land or through technological CO_2 removal processes, from raw products to intermediary and final products to end of life of carbon.
Project accounting	Accounting for changes in GHG emissions and removals resulting from a specific project relative to a counterfactual baseline scenario or performance benchmark.
Proxy data	Data from a similar process or activity that is used as a stand-in for the given process or activity without being customized to be more representative of the given process or activity.
Remote sensing-based calculation	Calculation that uses satellite or aerial data for a specific land-based activity.
Removal	The transfer of a greenhouse gas from the atmosphere to storage within a pool. Removals can be from biogenic or technological sinks and stored in land-based, product or geologic carbon pools.
Reversal	An emission from a carbon pool that stores carbon associated with a removal that was previously reported by the reporting company.
Secondary data	Data that is not from specific activities within a company's value chain.
Segregation	Chain of custody model in which specified characteristics of a material or product are maintained from the initial input to the final output.
Significance threshold	A qualitative or quantitative criteria used to define a significant structural change. It is the responsibility of the company/ verifier to determine the "significance threshold" for considering base year emissions recalculation. In most cases the "significance threshold" depends on the use of the information, the characteristics of the company, and the features of structural changes.

Sink	Any biological or technological process, activity or mechanism that removes greenhouse gases from the atmosphere.
Soil carbon pool	Carbon in soil minerals and organic matter less than 2 mm in size. Includes mineral soil organic carbon, organic soil organic carbon and soil inorganic carbon pools.
Soil inorganic carbon pool	Carbon in soil carbonates and other mineral carbon forms.
Source	Any process, activity or mechanism that releases greenhouse gases into the atmosphere.
Sourcing region	A predefined, spatially explicit land area that supplies harvested biogenic materials to the first collection point or processing facility in a value chain. Sourcing regions are also referred to as a supply shed or supply base.
Stationary combustion	Burning of fuels to generate electricity, steam, heat, or power in stationary equipment such as boilers, furnaces etc.
Statistical land use change (sLUC) emissions	Emissions (primarily from carbon stock losses) due to recent (previous 20 years or more) land conversion within a landscape or jurisdiction. sLUC can serve as a proxy for dLUC where specific sourcing lands are unknown or when there is no information on the previous states of the sourcing lands.
Stock-change accounting	Accounting methods that estimate the net fluxes of carbon to and from the atmosphere based on the net change in carbon stocks in the system.
Target boundary	The boundary that defines which GHGs, scopes, geographic operations, sources, sinks, pools, and activities are covered by the target.
Target commitment period	The period of time during which emissions performance is actually measured against the target. It ends with the target completion date.
Target completion date	The date that defines the end of the target commitment period and determines whether the target is relatively short- or long-term.
Technological CO_2 removal (TCDR)-based product carbon pool	Carbon in products or materials derived from technological CO_2 removals processes.

Technological CO_2 removal (TCDR) carbon cycle	Carbon cycle pathway that includes technological CO_2 removals, transfers of TCDR-based carbon between carbon pools, and TCDR-based CO_2 emissions.
Technological CO_2 removal (TCDR)-based carbon	Carbon derived from technological CO_2 removal processes.
Technological CO_2 removal (TCDR)-based product carbon pool	Carbon in products or materials derived from technological CO_2 removals processes.
Technological CO_2 removals	CO_2 removals resulting from atmospheric CO_2 transferred via technological sinks to storage in TCDR-based product or geologic carbon pools.
Technological sinks	Mechanical or chemical processes that remove CO_2 from the atmosphere and store CO_2 or TCDR-based carbon in non-atmospheric carbon pools.
Technological CO_2 removals	CO_2 removals resulting from atmospheric CO_2 transferred via technological sinks to storage in product or geologic carbon pools.
Thirty party assurance	Person(s) from an organization independent of the GHG inventory process conducts third party assurance. (Also called “External assurance.”)
Traceability	The ability of a company to identify, track, and collect information on activities in its value chain, across its upstream and downstream processes and products.
Uncertainty range	The range of possible values for a specified confidence level that contain the true value for the estimate.
Verification	An independent assessment of the reliability (considering completeness and accuracy) of a GHG inventory.
Waste	An output of a system that has no market value.
Yield	The amount of agriculture or forestry product harvested per area of land over a certain time.

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GREENHOUSE GAS PROTOCOL

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

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