LEVERAGING LCA TO STRENGTHEN GHG PROTOCOL CORPORATE ACCOUNTING

Technical Report 1: Comparison of the GHG Protocol and LCA frameworks

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POLYTECHNIQUE MONTRÉAL
UQÀM
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AUTHORS

Nicolas Roy Heppell, Analyst, Polytechnique Montréal
Lucie Leignier, Analyst, Université du Québec à Montréal (UQÀM)
Elliot Muller, Analyst, Polytechique Montréal
Kathryn Loog, PhD Student, Polytechnique Montréal

CONTRIBUTORS

Maxine Létourneau, PhD Student, UQÀM
Julien Pedneault, Analyst, Polytechnique Montréal
François Saunier, CIRAIG Deputy Director, Polytechnique Montréal

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ABBREVIATIONS AND ACRONYMS

APOS	Allocation at the Point of Substitution
CFC	Chlorofluorocarbon
CFF	Circular Footprint Formula
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	CO_2 equivalent
dLUC	Direct land use change
EF	Environmental Footprint
EPD	Environmental Product Declaration
GHG	Greenhouse gas
GTP	Global temperature potential
GWP	Global warming potential
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
ILCD	International Reference Life Cycle Data System
iLUC	Indirect land use change
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
jdLUC	Jurisdictional direct land use change
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LUC	Land use change
LULUC	Land use and land use change
LULUCF	Land use, land use change and forestry
NF_3	Nitrogen trifluoride
N_2O	Nitrous oxide
NGO	Non-Governmental Organization
O-LCA	Organizational life cycle assessment
PEF	Product Environmental Footprint
PCR	Product Category Rules

PFC	Perfluorocarbon
REC	Renewable Energy Certificate
RNG	Renewable natural gas
SBTi	Science Based Targets Initiative
sLUC	Statistical land use change
SF_6	Sulphur hexafluoride
TCDR	Technological carbon dioxide removal
T&D	Transmission and distribution
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

GLOSSARY

Auxiliary activities	Activities necessary for running the organization that markets a product or a service, but that are not directly related with the product or service's life cycle (e.g., employee commuting).
Avoided emissions	GHG emissions that are prevented as a result of an organization's action(s), compared to alternative scenarios without the action(s) (GHG Protocol, 2022b).
Background system	The background system consists of processes on which no or, at best, indirect influence may be exercised by the decision-maker for which an LCA is carried out. Such processes are called "background processes" (Life Cycle Initiative, n. d.).
Base year	A historic datum (a specific year or an average over multiple years) against which a company's emissions are tracked over time (GHG Protocol, 2022b).
Biogenic carbon	Carbon in, or derived from, living organisms or biological processes, but not including fossilized materials or those from fossil sources (GHG Protocol, 2022b).
Biogenic product emission	CO_2 emissions from combustion or biodegradation of biogenic products.
Biogenic product removal	CO_2 removals where the carbon is stored in biogenic products.
Carbon offset	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 organization's value chain (GHG Protocol, 2022b).
Characterization factor	A factor that enables the conversion of the inventory (input and outputs) into environmental impact indicators.
Consolidation	Combination of GHG emissions data from separate operations that form part of one organization or group of organizations (GHG Protocol, 2015a).
Cradle-to-gate	An assessment that includes part of the product's life cycle, including material acquisition through the production of the studied product and excluding the distribution, use and end-of-life stages (Life Cycle Initiative, n. d.).
Cradle-to-grave	A cradle-to-grave assessment considers impacts at each stage of a product's life cycle, from the time natural resources are extracted from the ground and processed through each subsequent stage of manufacturing, transportation, product use, recycling, and ultimately, disposal (Life Cycle Initiative, n. d.).
Direct emissions	Emissions from sources that are owned or controlled by the reporting organization (GHG Protocol, 2022b).
Foreground system	The foreground system consists of processes which are under the control of the decision-maker for which an LCA is carried out. They are called "foreground processes" (Life Cycle Initiative, n. d.).
Gate-to-gate	An assessment that includes a single activity (e.g., a production stage) or a group of activities within the life cycle (i.e., a part of the life cycle).
GHG inventory	Quantified list of an organization's GHG emissions and sources (GHG Protocol, 2011a)

Indirect emissions	Emissions that are a consequence of the activities of the reporting organization, but occur at sources owned or controlled by another organization (GHG Protocol, 2022b).
Land use	Use of a specific area of land for a particular purpose with a certain level of intensity that reflects land management practices.
Land use change	A transition from one land use category to another, such as from forest to grassland or cropland (GHG Protocol, 2022b).
Land management emissions	Emissions resulting from ongoing land management practices.
Minimum boundaries	Boundaries defined by the GHG Protocol to indicate the minimum emission sources to be included for each scope 3 category.
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 organization (GHG Protocol, 2022b).
Organization	All types of organizations (e.g., companies, non-governmental organizations, government agencies) that apply the set of standards and guidelines provided by the GHG Protocol to quantify corporate GHG emissions.
Organizational boundaries	The boundaries that determine the operations owned or controlled by the reporting organization, depending on the consolidation approach taken (equity or control approach) (GHG Protocol, 2015a).
Pool	A physical reservoir or medium where a GHG or its constituent elements are stored (GHG Protocol, 2022b).
Reporting organization	The organization for which organizational GHG emissions are accounted for.
Reporting period	The period for which organizational GHG emissions are accounted for.
Scope	Defines the operational boundaries in relation to indirect and direct GHG emissions (GHG Protocol, 2015a).
Scope 1 emissions	A reporting organization's direct GHG emissions (GHG Protocol, 2015a).
Scope 2 emissions	A reporting organization's emissions associated with the generation of electricity, heating/ cooling, or steam purchased for own consumption (GHG Protocol, 2015a).
Scope 3 emissions	A reporting organization's indirect emissions other than those covered in scope 2 (GHG Protocol, 2015a).

INTRODUCTION

The development of organizational greenhouse gas (GHG) inventories has experienced remarkable growth in recent years. The GHG Protocol has established itself as the primary reference framework guiding organizations in conducting such assessments. However, despite its widespread adoption, the GHG Protocol presents certain limitations, and several operational challenges arise when implementing GHG inventories in accordance with its standards and guidelines.

The main objective of this work is to identify how life cycle assessment (LCA) practices and tools can support the process of quantifying GHG emissions at the organizational level and strengthen its methodological robustness.

This work is structured into four documents, each with the specific objectives:

- *Technical Report 1: Comparison of the GHG Protocol and LCA frameworks*. This report aims to compare the GHG Protocol and LCA frameworks across a wide range of methodological aspects, highlighting their differences, similarities, and potential inconsistencies.
- *Technical Report 2: Life Cycle Data and its Use for Corporate GHG Accounting*. This report aims to present and describe the different types of data (i.e., emission factors) typically used to develop organizational GHG inventories, outlining their respective strengths and limitations.
- *Technical Report 3: Guidelines for Improved Corporate GHG Accounting*. This report aims to provide guidelines for improving the consistency, transparency, and robustness of organizational GHG inventories, drawing on life cycle thinking and practices.
- *Summary Report*. This report summarizes the main aspects of the three technical reports.

This document constitutes *Technical Report 1*. It focuses on the differences and overlaps between organizational carbon accounting – as applied under the GHG Protocol – and life cycle assessment (LCA)[1].

The document is structured in subsections, each comparing the two approaches on a specific aspect. These aspects are:

1. Reporting unit;
2. Boundaries;
3. Capital goods;
4. Greenhouse gases and indicators;
5. Electricity accounting;
6. Biogenic carbon;
7. Land use and land use change;
8. Multifunctionality;
9. Avoided emissions;
10. Reporting and results interpretation.

[1] Both product and organizational LCA.

The subsequent documents of this work focus on the different types of data used to model activities, namely process-based and environmentally extended input-output (EEIO) emission factors, and provide guidance to support practitioners in improving the robustness of GHG inventories, particularly from the perspective of LCA best practices. Their content builds on the concepts introduced in *Technical Report 1*; readers are therefore encouraged to read that document beforehand.

The main findings set out in this document remain applicable at the time of writing. However, the GHG Protocol is currently in the process of updating its suite of corporate standards and guidance. Once published, the revised standards and guidance should supersede the aspects presented herein where differences or inconsistencies arise.

1. OVERVIEW OF THE COMPARISON

Comparing the GHG Protocol and LCA is complex because these two frameworks differ in both their objectives and application contexts. More specifically, two key distinctions stand out in this comparison.

First, they apply to different subjects. The specific approach of the GHG Protocol studied in this report, that is the *Corporate Standard* and underlying standards and guidance, applies only to organizations. Conversely, LCA applies to a wide range of subjects, including products, services, processes, and organizations. The *ISO 14072* (ISO, 2024) standard, covering organizational LCA, could be specifically compared to that of the GHG Protocol. Nevertheless, this report takes a broader view, and examinates how LCA approaches can facilitate the process of quantifying organizational GHG emissions and improve its robustness. As such, the LCA approach as a whole is compared with the GHG Protocol's requirements and recommendations in the next sections.

Second, given its specific application domain, the GHG Protocol describes a relatively detailed approach and prescribes certain methodological choices (e.g., on boundaries). Conversely, a wide range of standards and approaches exist within the LCA community, making it impossible to capture all of them within this analysis. For this reason, the **general LCA framework** – *ISO 14040/44* – is used here as the main point of reference, while also considering certain underlying approaches (e.g., *ISO 14072* for organizational LCA). There is therefore a notable disparity in the level of detail and methodological requirements. Nonetheless, the comparison focuses on the range of practices and considerations outlined in the general LCA framework against those of the **GHG Protocol**.

The following sections describe both approaches and then compare them based on the methodological aspects summarized in Table 1-1.

Table 1-1: Methodological aspects compared in this report

Methodological aspect	Description
Reporting unit	Unit of analysis (i.e., to what results are scaled to).
Boundaries	Categorization of activities and inclusion requirements.
Capital goods	Treatment of assets that have an extended lifetime.
Greenhouse gases and indicators	Included greenhouse gases and studied indicators.
Electricity accounting	Treatment of electricity flows (i.e., location-based and market-based methods).
Biogenic carbon	Accounting methods for biogenic carbon flows (removals, biogenic carbon dioxide [CO_2] emissions) and reporting requirements.
Land use and land use change	Inclusion of land use change (LUC) metrics and reporting requirements.
Multifunctionality	Treatment of multifunctionality for co-products and end-of-life allocation.
Avoided emissions	Inclusion and treatment of avoided emissions and reporting requirements.
Reporting and results interpretation	Main reporting requirements and main analyses supporting results interpretation.

1.1 GHG Protocol

The GHG Protocol is a widely used accounting framework for businesses and governments to understand, quantify, and manage their GHG emissions. The GHG Protocol was developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). Its development began in the late 1990s, and the first version of the *GHG Protocol Corporate Accounting and Reporting Standard* (hereinafter referred to as the "*Corporate Standard*") was released in 2001. It has since been updated and revised to incorporate stakeholder feedback and refine its requirements and guidance.

The *Corporate Standard* provides guidelines for companies and other organizations (e.g., Non-Governmental Organizations [NGOs], government agencies) to measure and report their GHG emissions, encompassing scope 1 (direct emissions), scope 2 (indirect emissions from purchased energy), and scope 3 (indirect emissions in the value chain) emissions. Many organizations worldwide use it for voluntary disclosure, setting targets, and contributing to climate action. The objectives of the *Corporate Standard* are as follows (GHG Protocol, 2015a):

- "To help companies prepare a GHG inventory […] through the use of standardized approaches and principles."
- "To simplify and reduce the costs of compiling a GHG inventory."
- "To provide business with information that can be used to build an effective strategy to manage and reduce GHG emissions."
- "To provide information that facilitates participation in voluntary and mandatory GHG programs."
- "To increase consistency and transparency in GHG accounting and reporting among various companies and GHG programs."

While the GHG Protocol remains widely adopted internationally as a standard for corporate GHG accounting, the organization has published multiple standards and guidance documents. These resources apply to different actors (companies, cities, government bodies, etc.) and subjects (products, organizations, projects, etc.). In this document, the term "GHG Protocol" refers to the set of standards and guidelines provided by the entity that relate to the quantification of corporate GHG emissions, as presented in Table 1-2.

Table 1-2: Corporate-level GHG Protocol standards and guidance

Standards and Guidance	Description
Corporate Accounting and Reporting Standard (GHG Protocol, 2015a)	Provides requirements and guidance for companies and other organizations (NGOs, government agencies, etc.) that are preparing a corporate-level GHG inventory. This standard is hereinafter referred to as the ***Corporate Standard***.
Corporate Value Chain (Scope 3) Standard (GHG Protocol, 2011)	Provides requirements and guidance for companies and other organizations to assess their entire value chain GHG emissions (i.e., indirect emissions). This standard is hereinafter referred to as the ***Scope 3 Standard***.
Scope 2 Guidance (GHG Protocol, 2015b)	Provides guidance on how organizations estimate emissions from purchased or acquired electricity, steam, heat, and cooling (called "scope 2 emissions"). It was published as an amendment to the *Corporate Standard*.

Standards and Guidance	Description
Scope 3 Calculation Guidance (GHG Protocol, 2013a)	Serves as a complement to the *Scope 3 Standard* and provides practical guidance on calculating scope 3 GHG emissions of organizations.
Agriculture Guidance	Acts as a supplement to the *Corporate Standard* and provides guidance to estimate GHG emissions for organizations in the agricultural sector. The *Agricultural Guidance* focuses particularly on direct emissions (scope 1).
Land Sector and Removals Standard	Building on the *Corporate Standard* and *Scope 3 Standard*, this standard provides requirements and recommendations for accounting and reporting GHG emissions and removals from activities in the land sector, as well as other CO_2 removal technologies.

Many other GHG Protocol resources are intended for other types of actors or subjects. They are briefly described in Table 1-3.

Table 1-3: Other GHG Protocol resources

Standards and Guidance	Description
GHG Protocol for Cities	Provides a framework for accounting and reporting city-wide GHG emissions.
GPC Supplemental Guidance for Forest and Trees	Provides cities and other communities with a robust, transparent, and worldwide applicable framework to consistently identify, calculate, and report on GHG emissions and removals by forests and trees within communities' boundaries.
Mitigation Goal Standard	Provides guidance for designing national and subnational mitigation goals and a standardized approach for assessing and reporting progress toward goal achievement.
Land Use, Land-Use Change, and Forestry (LULUCF) Guidance for GHG Project Accounting	Provides more specific guidance and uses more appropriate terminology and concepts to quantify and report GHG reductions from LULUCF project activities.
Policy and Action Standard	Provides a standardized approach for estimating the GHG effect of policies and actions.
Product Standard	Provides a framework for estimating a product's GHG emissions over its life cycle.
Project Protocol	Provides an accounting tool to quantify the benefits (i.e., emission reductions) of a climate change mitigation project.
Guidelines for Grid-Connected Electricity Projects	Supplements the *Project Protocol* and provides guidance on special considerations for project activities that reduce consumption of grid electricity.
Public Sector Protocol	Provides guidance that interprets the principles from the *Corporate Standard* for the unique structures and needs of United States government operations at the federal, state and local levels.
Estimating and Reporting Avoided Emissions	Provides a neutral framework for estimating and disclosing both the positive and negative impacts of products and offers recommendations for companies to improve the credibility and consistency of claims about the comparative GHG impacts of their products.
Potential Emissions from Fossil Fuel Reserves	Provides guidance for measuring and reporting the potential GHG emissions from the fossil fuel reserves held by oil, coal and gas companies.

In this document, the term “organization” refers to all types of organizations (e.g., companies, NGOs, government agencies) that may apply the set of standards and guidance provided by the GHG Protocol to quantify corporate GHG emissions. The term “reporting organization” refers to the organization calculating its GHG inventory.

1.2 Life cycle assessment

Life cycle assessment is a method used to evaluate the potential environmental impacts of a product, process, service or organization throughout its entire life cycle, from raw material extraction to end-of-life. The concept of LCA emerged in the 1970s as a response to increasing environmental concerns and the need for a systematic approach to assess the environmental performance of products.

The International Organization for Standardization (ISO) played a crucial role in standardizing LCA methodologies. In 1997, ISO published the first LCA standard, *ISO 14040* (ISO, 2022), providing guidelines for conducting life cycle assessments. This was followed by *ISO 14044* in 2006 (ISO, 2006), which further refined the LCA methodology. Table 1-4 highlights the main LCA-related standards and guidance documents.

Table 1-4: Main LCA-related standards and guidance documents

Standard	Description
ISO 14040/44	*ISO 14040* defines the principles and framework of LCA and *ISO 14044* specifies requirements and provides guidelines for LCA.
ISO 14020/21/24/25/26	Set out principles, requirements and guidelines for the development and use of environmental labels and declarations, as well as for the communication of footprint information.
ISO 14046:2014	Sets out "principles, requirements and guidelines related to water footprint assessment of products, processes and organizations based on life cycle assessment".
ISO 14067:2018	Specifies principles, requirements and guidelines for the quantification and reporting of the carbon footprint of a product, in a manner consistent with *ISO 14040/44* for LCA.
ISO 14071:2024	Provides additional requirements and guidance for *ISO 14040* and *ISO 14044*, specifying how to conduct a critical review of any type of LCA study and the competencies required for such a review.
ISO 14072:2024	Technical specification that sets out "additional requirements and guidelines for an effective application of *ISO 14040* and *ISO 14044* to organizations". The application of LCA to organizations is referred to as organizational LCA (O-LCA).
ILCD Handbook	The International Reference Life Cycle Data System (ILCD) handbook provides comprehensive guidance to improve consistency and quality assurance in applying LCA.
Product Environmental Footprint (PEF)	Harmonized LCA framework published by the European Commission to measure and communicate the environmental performance of products and organizations.
PAS 2050	"Specifies requirements for the assessment of the life cycle GHG emissions of goods and services (collectively referred to as "products") based on key life cycle assessment techniques and principles."

More recently, various industries and sectors have developed their own LCA standards and guidelines to address specific challenges and nuances in their respective domains (e.g., *EN 15804* for environmental product declarations [EPD] of construction products, *ISO 20915* (ISO, 2018) for LCAs of steel products). Despite a tenfold increase in the number of LCA-related standards, *ISO 14040* and *ISO 14044* (hereinafter referred to as *ISO 14040/44*) remain the core and most widely used LCA standards. Their main objectives are as follows:

- "Identifying opportunities to improve the environmental performance of products at various points in their life cycle."
- "Informing decision-makers in industry, government or non-government organizations (e.g. for

the purpose of strategic planning, priority setting, product or process design or redesign).”

- “Marketing (e.g. implementing an ecolabelling scheme, making an environmental claim, or producing an environmental product declaration).”

In this document, the term “LCA” broadly refers to the LCA field, with emphasis on the generic framework provided by *ISO 14040/44* and the organizational LCA standard *ISO 14072*. The former is referred to as “product LCA” and the latter as “organizational LCA” (O-LCA).

2. REPORTING UNIT

2.1 Reporting unit in the GHG Protocol

The GHG Protocol's *Corporate Standard* defines a reference basis for the GHG inventory. This basis is **one year of an organization's activities** and is called the *reporting year*. It can be either a calendar or financial year, at the reporting organization's discretion.

To track performance over time and set reduction targets, emissions can be calculated for a base year of activities against which future emissions can be compared. The base year is usually a one-year period, but it is also possible to choose an average of annual emissions over several consecutive years. A multi-year average can help smooth unusual fluctuations when a single year would not be representative of the organization's typical emissions profile.

Finally, the reporting unit used in the GHG Protocol currently does not aim to compare GHG emissions between organizations, as no two organizations will have the same size, structure, or product mixes. Rather, the reporting unit of "one year of activities" enables an organization to compare its emissions over time.

2.2 Reporting unit in LCA

2.2.1 Product LCA

In product LCA, the reporting unit used as the reference basis for all calculations in the life cycle impact assessment is called the *functional unit*. The functional unit aims to capture the **function of the product or system under study** and can vary considerably depending on the studied system and the study's objectives.

Functional units also serve as a basis for comparing products or systems that perform the same function. As such, the performance of the product or system (e.g., efficiency, capacity, lifespan) must be considered when defining the functional unit, as illustrated in Box 2-1.

Box 2-1: Including performance in the functional unit

To compare two pairs of shoes, one of high quality lasting three years and another of lower quality lasting six months (assuming the same amount of walking per day), the lifespan difference must be considered. The functional unit can be defined as "Protecting one's feet while walking X km per day for one year," thereby including a temporal component that addresses this difference in the product's lifespan. Here, only one-third of the higher-quality shoes would be needed to fulfill the functional unit, but two pairs of the lower-quality shoes would be needed.

2.2.2 Organizational LCA

In O-LCA, the reporting unit is the **time period** during which the organization's activities are assessed. This period can be a financial year, but it may also be any other defined timeframe. The chosen period must be clearly stated in the study (ISO, 2024).

As with the GHG Protocol, the reporting unit in O-LCA does not aim to compare GHG emissions between organizations, as organizations' activities and study boundaries differ.

2.3 Comparison of approaches – Reporting unit

The main differences between GHG Protocol and LCA reporting units mainly lie in the temporality and the comparability. On the one hand, in both the **GHG Protocol** and **O-LCA**, reporting units are defined over a period of time. In the GHG Protocol, this period is one year, whereas in O-LCA, the time frame can be selected based on the study's objective. Neither enables the comparison of GHG emissions between organizations.

In contrast, the functional unit in **product LCA** is grounded in the system's function: it defines the quantified performance of a product system. This anchors the assessment to the provided function, ensuring results are comparable across alternatives that fulfill the same function.

3. BOUNDARIES

3.1 Boundaries in the GHG Protocol

In the GHG Protocol's *Corporate Standard*, the definition of system boundaries is standardized. Two types of boundaries need to be defined: *organizational* and *operational boundaries*.

3.1.1 Organizational boundaries

Organizations can have different legal and structural arrangements. For example, some are involved in subsidiaries, joint ventures, or even partnerships. Therefore, defining **organizational boundaries** involves choosing an approach to **consolidate emissions from the various reporting organization' operations**. The *Corporate Standard* defines an *operation* as any "facility, subsidiary, affiliated company or other form of joint venture" in which the reporting organization may be involved (GHG Protocol, 2015a). The term *consolidation* refers to combining GHG emissions values from separate operations that form the reporting organization.

The *Corporate Standard* defines two consolidation approaches, based on financial accounting principles:

- The **equity share approach**, where the reporting organization accounts for the GHG emissions of an operation according to its financial participation in the operation. It is also called *equity share*. This approach implies that the more a reporting organization invests in an operation, the more emissions from that operation are attributed to the organization. The equity share represents the economic interest of the reporting organization in an operation (i.e., the share of financial gains and liabilities the organization holds in the operation). In most cases, the equity share equals the ownership percentage.

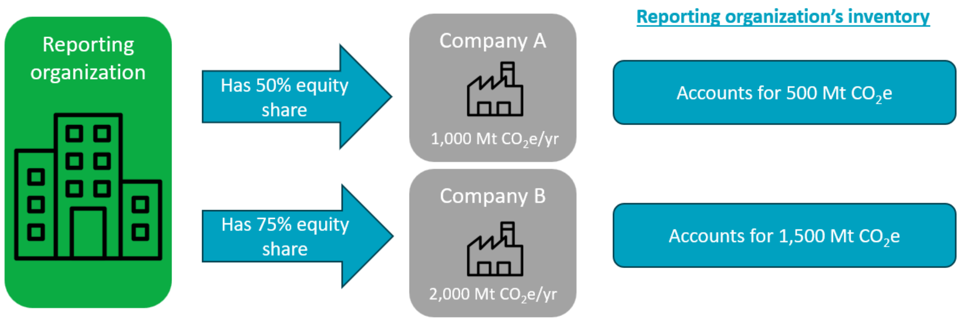
- The **control approach**, where the reporting organization accounts for 100% of emissions from operations over which it has control, and none from those it does not control. Organizations using the control approach must choose between the operational or financial control criteria:

    a) **Operational control**: there is operational control if the reporting organization (or one of its subsidiaries) has full authority to introduce and implement its own operating policies in the operations of another organization. Operational control primarily occurs when the reporting organization can manage daily operations, even if it does not have the authority to make all operational decisions.

    b) **Financial control**: there is financial control if the reporting organization can direct the financial and operating policies of another organization's operations, with a view to gaining economic benefits from its activities.

Box 3-1 and Box 3-2 present simplified examples of the equity share approach and the operation control respectively. However, applying these consolidation approaches is more complex in practice, and further information is provided in section 3.1.3.

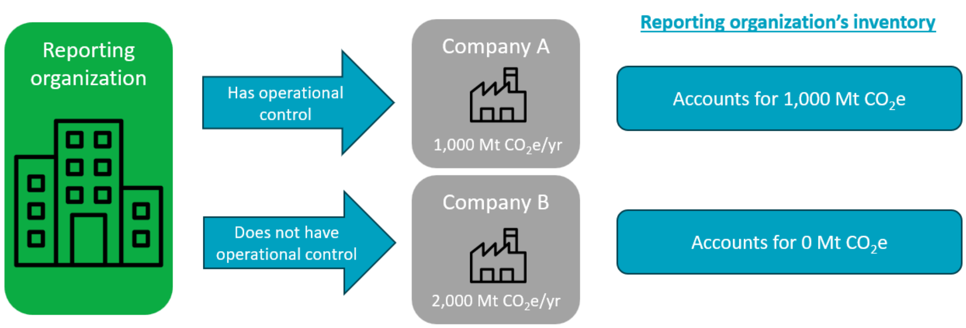
Box 3-1: Example of the equity share approach



Note: Reproduced from the *GHG Protocol Corporate Training Webinar: Day 1*, by GHG Protocol, 2019. *https://ghgprotocol.org/corporate-standard-training-webinar*.

In this example, the reporting organization holds a 50% financial participation in company A and 75% in company B. Under the equity share approach, the reporting organization accounts for emissions in proportion to its ownership share in the companies. Therefore, it will account for 50% of company A's emissions (i.e., 500 Mt of CO_2 equivalent [CO_2e]) and 75% of company B's emissions (i.e., 1,500 Mt CO_2e), respectively.

Box 3-2: Example of the operational control approach



Note: Reproduced from the *GHG Protocol Corporate Training Webinar: Day 1*, by GHG Protocol, 2019. *https://ghgprotocol.org/corporate-standard-training-webinar*.

In this example, the reporting organization has operational control over company A but not over company B. Under the operational control approach, the reporting organization accounts for 100% of emissions from companies over which it has control. Therefore, it will account for 100% of company A's emissions (i.e., 1,000 Mt CO_2e) and 0% of company B's emissions, respectively.

In the specific situation where the reporting organization applies the **financial control approach** but is involved in a **joint venture**, emissions from the joint venture's operations where the reporting organization has financial control must be accounted for based on the **equity share** (and not 100%), to reflect the proportionate interest of each organization involved in the joint venture[2].

However, under the **control approach**, emissions from franchises, investments and other contractual agreements are considered differently. Even if the reporting organization does not have control over those entities, their associated emissions are not necessarily excluded from the reporting organization's inventory. This is further discussed in section 3.1.2, in the definition of operational boundaries.

Organizations can apply either consolidation approach. Once the consolidation approach is selected, organizations must apply it consistently across all levels and operations to ensure a consistent inventory.

3.1.2 Operational boundaries

Defining **operational boundaries** consists **of identifying emissions associated with the reporting organization's entities and operations** that are included in the GHG inventory, and classifying them into emission **scopes** and **categories**.

The *Corporate Standard* categorizes emissions as either *direct* or *indirect*, and organizes them into three distinct scopes that are:

- *Scope 1*: direct emissions originating from sources that are owned or controlled by the reporting organization (e.g., combustion emissions of a vehicle owned by the organization).
- *Scope 2*: indirect emissions originating from the generation of purchased energy consumed by the organization (electricity, heat, steam, cooling).
- *Scope 3*: other indirect emissions originating from the organization's value chain. According to the *Scope 3 Standard*, scope 3 is split into 15 emission categories that cover the organization's value chain. Moreover, the *Scope 3 Standard* distinguishes *upstream* and *downstream scope 3 emissions* (also referred to as "upstream and downstream activities"), based on an accounting approach. Upstream scope 3 emissions are indirect GHG emissions related to the goods or services purchased or acquired by the organization (i.e., emissions from activities the organization pays for). In contrast, downstream scope 3 emissions are indirect GHG emissions related to goods and services sold by the organization (i.e., emissions from activities the organization does not pay for).

Table 3-1 provides a description of the main scope 1 and 2 emission sources and the 15 scope 3 categories. However, scope 1 emissions can originate from several other sources, depending on the organization's activity sector (e.g., farming or livestock breeding, waste treatment).

In practice, when defining operational boundaries, the organization must decide which emission sources to include. The GHG Protocol's *Corporate Standard* requires the reporting of scope 1 and 2 emissions, and recommends the inclusion of **relevant** scope 3 emissions. The relevance of an emission source can be assessed based on several factors[3]:

- **Significance**: significance of the emissions source (relative to scopes 1 and 2 emissions).

[2] See Chapter 3 of the *Corporate Standard* (GHG Protocol, 2015a).

[3] See Chapter 4 of the *Corporate Standard* (GHG Protocol, 2015a).

- **Importance for stakeholders**: the extent to which the source is deemed critical by stakeholders (customers, investors).
- **Influence**: the organization's ability to reduce emissions from the source.
- **Reliability of data**: the extent to which data of acceptable quality is available.
- **Exposure to GHG risks and opportunities**.

In contrast, the *Scope 3 Standard* requires the inclusion of emissions from scopes 1, 2, and 3. Therefore, organizations following the *Scope 3 Standard* must account for all scope 3 emissions to ensure completeness. Nevertheless, the standard acknowledges that certain emission sources may be challenging to account for. Their exclusion is allowed, provided it is appropriately justified[4] (GHG Protocol, 2011).

[4] See Chapter 6 of the *Scope 3 Standard* (GHG Protocol, 2011a).

Table 3-1: Description of emission sources and categories by scope

Scope	Emission sources/categories	Description
Scope 1	Stationary combustion	Emissions from fuel combustion in fixed equipment (e.g., boilers, furnaces) owned or controlled by the organization.
	Mobile combustion	Emissions from fuel used in mobile equipment (e.g., vehicles, industrial trucks) owned or controlled by the organization.
	Fugitive emissions	Emissions associated with refrigerant leaks from cooling equipment (e.g., air conditioning).
	Process emissions	Emissions from physical or chemical processes (e.g., cement production, on-site biomethanization).
Scope 2	Purchased electricity, steam, heat and cooling	Emissions associated with the combustion of fuels on the site where the energy purchased is produced.
Scope 3 – Upstream	1. Purchased goods and services	Emissions from the production of goods and services that the organization buys.
	2. Capital goods	Emissions from the production/construction of capital equipment (e.g., machinery, IT equipment, buildings).
	3. Fuel-and-energy related activities	Emissions from extraction, production, and transportation of fuels and energy purchased not included in scope 1 or 2, i.e.: • Upstream emissions of purchased fuels (extraction, production, transportation). • Upstream emissions of purchased energy (extraction, production, and transportation of fuels consumed in the generation of energy). • Transmission and distribution losses (T&D) emissions.
	4. Upstream transportation and distribution	Emissions from transport and distribution of goods purchased by the organization, between the organization’s tier 1 suppliers and its own operations (in vehicles not owned or operated by the organization). Emissions from other transportation and distribution services purchased by the organization (e.g., transportation between the organization’s facilities, transportation of sold products to clients), including retail and storage.
	5. Waste generated in operations	Emissions from waste treatment (e.g., disposal, incineration, composting) generated by the organization (including wastewater treatment).
	6. Business travel	Emissions from employee travel related to the organization's activities, excluding commuting to and from work, in vehicles not owned or controlled by the organization (including meals and hotel accommodation).
	7. Employee commuting	Emissions from the daily travel of employees between home and work, in vehicles not controlled by the organization.
	8. Upstream leased assets	Emissions from leased assets not included in scope 1 and scope 2.
Scope 3 – Downstream	9. Downstream transportation and Distribution	Emissions from transport and distribution of sold product between the organization’s operations and the end consumer (when not paid for by the organization), including retail and storage.
	10. Processing of sold products	Emissions from processing intermediate products sold to third parties (e.g., manufacturers).
	11. Use of sold products	Emissions from the use phase of sold goods and services (e.g., electricity).
	12. End-of-life treatment of sold products	Emissions from waste treatment of products sold by the organization in the reporting year (e.g., disposal, recycling).
	13. Downstream leased assets	Emissions from assets the company owns but leases to others that are not included in scope 1 and scope 2 and reported by the lessor.
	14. Franchises	Emissions from operations of franchises not directly owned by the company, not included in scope 1 and scope 2 reported by the franchisor.
	15. Investments	Emissions from investments (e.g., equity and debt investments) that are not included in scope 1 and scope 2.

3.1.3 Operational boundaries for activities under contractual agreements

The choice of the consolidation approach influences how emissions from **franchises (category 14), investments (category 15) and leased assets (categories 8 and 13)** are categorized in the reporting organization's GHG inventory, either as scope 1, scope 2 or scope 3 emissions.

a) Franchises and investments

Under the **equity share approach**, the reporting organization accounts for the emissions of each entity in which it holds an equity share — including franchises and other entities in which it has an investment — in proportion to that share, across all three scopes. For example, organization A, holding a 50% equity share in organization B, includes 50% of organization B's scope 1, 2, and 3 emissions in its own GHG inventory. This approach applies only where an equity share exists. Investments that carry no equity stake, such as bonds, debt instruments, and project finance, are not consolidated in this way; they are addressed separately under scope 3, category 15 (Investments), using methods specific to each instrument.

If the reporting organization applies the **control approach** (operational or financial), emissions from investments and franchises are consolidated differently in the reporting organization's GHG inventory depending on whether these operations are within or outside its organizational boundaries (i.e., whether the reporting organization has control over the operation). More precisely:

- *Case 1*: Under the **operational control** approach, a reporting organization that **has control** over a franchise or an investment (e.g., subsidiary) must account for the associated emissions in its own GHG inventory. Accordingly, 100% of scope 1, 2, and 3 emissions from those franchises and investments are accounted for within the reporting organization's own scope 1, 2 and 3, respectively (i.e., scope 1 as scope 1, scope 2 as scope 2).
- *Case 2*: Under the **operational control** approach, a reporting organization that **does not have control** over a franchise or an investment must[5] account for some of the associated emissions in its own GHG inventory:
  - Scope 1 and 2 emissions from franchises are accounted for in category 14 (franchises) of the reporting organization's scope 3.
  - All scope 3 emissions from franchises may also be included in category 14 of the reporting organization's scope 3. However, their inclusion is optional as they are outside the minimum boundaries of category 14 (see section 3.1.4 for more information on minimum boundaries), though their inclusion is advised when scope 3 emissions from franchises are significant (GHG Protocol, 2013a).
  - Similarly, scope 1 and 2 emissions from investments are accounted for in category 15 (investments) of the reporting organization's scope 3, in proportion to its share of equity in the investee or operation. In addition, the GHG accounting approach depends on the type of financial investment. Tables 15.1 and 15.2 (p. 137-139) of the *Scope 3 Calculation Guidance* provide further guidance for GHG accounting from each type of financial investment. Scope 3 emissions from investments may also be included in category 15 of

[5] This is only a requirement if the reporting organization follows the *Scope 3 Standard*, in which the inclusion of scope 3 emissions is required.

the reporting organization’s scope 3 if they are significant, though they are outside the minimum boundaries.

- *Case 3*: Under the **financial control** approach, a reporting organization that **has control** over a franchise or an investment (e.g., subsidiary) must account for the associated emissions in its own GHG inventory. Emissions from scope 1, 2, and 3 from franchises or investments are accounted for within the reporting organization’s own scopes 1, 2 and 3 (i.e., scope 1 as scope 1, scope 2 as scope 2). The proportion of emissions accounted for by the reporting organization depends on the type of financial accounting operation, although it is generally 100%[6].
- *Case 4*: Under the **financial control** approach, when the reporting organization **does not have control** over a franchise or an investment, it must account for some of the associated emissions in its own GHG inventory, following the same procedure as in *Case 2* (i.e., the one for operational control).

In summary, the reporting organization’s scope 1, 2, and 3 emissions include scope 1, 2, and 3 emissions from franchises and investments that are within organizational boundaries. However, when franchises and investments are outside organizational boundaries, their scope 1 and 2 emissions are reported as scope 3 emissions in the reporting organization’s inventory (under different categories), and their scope 3 emissions can optionally be included in the reporting organization’s scope 3 inventory.

b) Leased assets

The consolidation of emissions from leased assets depends on both the **type of leasing arrangement** and the organization's selected **consolidation approach**.

The type of leasing arrangement can be either a *capital* or an *operating lease*. A capital lease “[...] enables the lessee to operate an asset and also gives the lessee all the risks and rewards of owning the asset”, whereas an operating lease “[...] enables the lessee to operate an asset [...] but does not give the lessee any of the risks or rewards of owning the asset” (GHG Protocol, 2006). The Appendix F of the *Corporate Standard* (GHG Protocol, 2006) provides further details on the two types of leasing arrangements.

Table 3-2 summarizes how emissions from leased assets should be categorized across the different scopes, depending on the type of leasing arrangement and on whether the reporting organization acts as a lessee or lessor. Box 3-3 provides an example of emissions consolidation from leased assets and operations under the control approach.

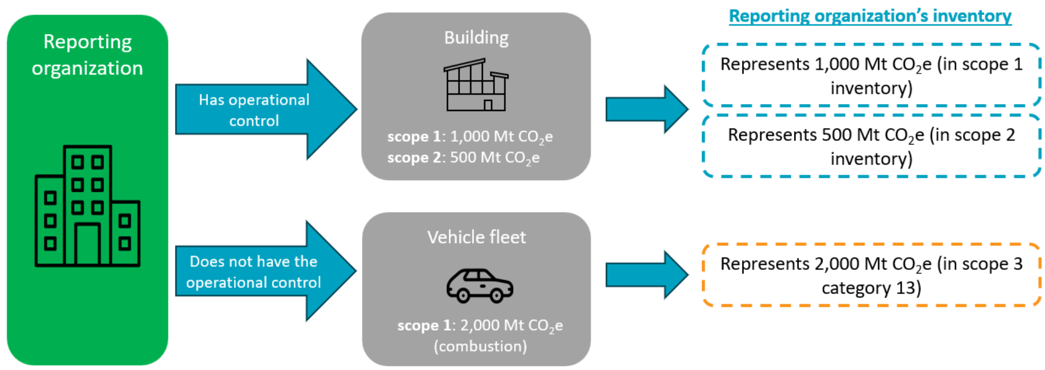
[6] As described in Table 1 (p. 19) of the *Corporate Standard* (GHG Protocol, 2015a), 100% of GHG emissions from subsidiaries, group companies, and franchises are accounted for in the reporting organization’s respective scopes. Emissions from non-incorporated joint ventures, partnerships, and operations where partners have joint financial control are accounted for in the reporting organization’s respective scopes based on the financial participation of the organization in the operation.

Table 3-2: Categorization of emissions from leased assets

Consolidation approach used	Type of leasing arrangement	
	Financial/Capital lease	**Operating lease**
Lessee’s Perspective (reporting organization is the lessee)		
Equity share or Financial Control	**Lessee has control**: scope 1, 2, and 3 emissions from the leased asset are accounted for in the reporting organization’s scope 1, 2, and 3, respectively.	**Lessee does not have control**: scope 1 and 2 emissions are accounted for in the reporting organization’s scope 3, in **category 8** (upstream leased assets). The asset’s scope 3 emissions can optionally be included, but they are outside the minimum boundaries (see section 3.1.4).
Operational control	**Lessee has control**: scope 1, 2, and 3 emissions from the leased asset are accounted for in the reporting organization’s scope 1, 2, and 3, respectively.	**Lessee has control**: scope 1 and 2 emissions from the leased asset are accounted for in the reporting organization’s scope 1, 2, and 3, respectively*.
Lessor’s perspective (reporting organization is the lessor)		
Equity share or Financial control	**Lessor does not have control**: scope 1 and 2 emissions from the leased assets are accounted for in the reporting organization’s scope 3, in **category 13** (downstream leased assets). The asset’s scope 3 emissions can optionally be included, but they are outside the minimum boundaries.	**Lessor has control**: scope 1, 2, and 3 emissions from the leased asset are accounted for in the reporting organization’s scope 1,2, and 3, respectively.
Operational control	**Lessor does not have control:** scope 1 and 2 emissions from the leased assets are accounted for in the reporting organization’s scope 3, in **category 13** (downstream leased assets). The asset’s scope 3 emissions can optionally be included, but they are outside the minimum boundaries.	**Lessor does not have control**: scope 1 and 2 emissions from the leased assets are accounted for in the reporting organization’s scope 3, in **category 13** (downstream leased assets). The asset’s scope 3 emissions can optionally be included, but they are outside the minimum boundaries*.
*: Operational control primarily occurs when the reporting organization has the ability to manage daily operations, even if it doesn't have the authority to make all operational decisions. However, some companies may be able to demonstrate that they do not have operational control over a leased asset held under an operating lease. In this case, the reporting organization may report emissions from the leased asset in scope 3 (category 8 or 13 depending on whether it is the lessee or the lessor), but the reason(s) that operational control is not perceived must be clearly stated in the GHG inventory report.		

Note: Reproduced from *Categorizing GHG Emissions with Leased Assets: Appendix F to the GHG Protocol Corporate Accounting and Reporting Standard – Revised Edition* (Table 1, p.3; Table 2, p.4), by GHG Protocol, 2006. https://ghgprotocol.org/sites/default/files/2022-12/Categorizing%20GHG%20Emissions%20from%20Leased%20Assets.pdf

Box 3-3: Example of leased asset emissions consolidation under the operational control approach



In this example, the reporting organization is a car leasing company and applies the **operational control** approach. The reporting organization leases a building from a third party for its offices and vehicle storage, under an **operating lease arrangement**. It also leases internal combustion engine vehicles to other companies under a **capital lease arrangement**.

According to Table 3-2, the reporting organization has operational control over the building. Therefore, scope 1 (i.e., 1,000 Mt CO_2e) and scope 2 (i.e., 500 Mt CO_2e) emissions associated with the building are accounted for in the reporting organization's respective scopes.

According to Table 3-2, the reporting organization does not have control over the vehicles leased to its clients. Therefore, emissions associated with vehicle fuel combustion (i.e., 2,000 Mt CO_2e) are included in the reporting organization's scope 3 inventory, in category 13 (downstream leased assets).

If the financial control approach were applied, the reporting organization would have control over the vehicles and emissions from fuel combustion would be accounted for in its scope 1 inventory.

3.1.4 Minimum boundaries

To support organizations with scope 3 reporting, the *Scope 3 Standard* introduces the concept of *minimum boundaries* (GHG Protocol, 2011a). The **minimum** boundaries define the emission sources that must **at a minimum be included in each emission category** to comply with the GHG Protocol. These boundaries serve as a baseline to prevent underreporting and to guide organizations in determining which upstream or downstream activities should be accounted for. Minimum boundaries help standardize emissions reporting, promote transparency, and support more credible and comprehensive carbon accounting across the value chain (GHG Protocol, 2011a).

Table 5.4 (p. 34-36) of the *Scope 3 Standard* describes the minimum boundaries for each scope 3 emission category[7]. Overall, the minimum boundaries of categories 1 (Purchased goods and services) and 2 (Capital goods) cover *cradle-to-gate* activities (i.e., activities from raw material extraction to the manufacturing

[7] See Section 5.4 of the *Corporate Value Chain (Scope 3) Standard* (GHG Protocol, 2011a).

plant exit, before distribution to the consumer). For the other scope 3 categories, the minimum boundaries include the activity's scope 1 and scope 2 emissions. For example, category 6 (Business travel) requires the inclusion of emissions from vehicle fuel combustion (e.g., plane, train, bus) at a minimum, or their electricity consumption in the case of electric vehicles.

Additionally, Table 5.4 (p. 34-36) of the *Scope 3 Standard* indicates, for each scope 3 category, the other life cycle emissions sources (e.g., fuel production, vehicle production) that can **optionally** be included in the organization's inventory. The latter are outside the minimum boundaries and are only indicative. Emission sources not explicitly mentioned as optional may be considered as implicitly optional[8]. Organizations can include additional emission sources from their value chain if those sources are considered relevant, provided that they are part of the activity's life cycle in question. Minimal boundaries generally include the largest emission sources of a scope 3 category (e.g., categories related to transportation include combustion emissions in the minimum boundaries which is the main emissions sources from transportation). However, in specific cases and for some categories, minimum boundaries may not include the main emission sources arising from the activity or the category (e.g., indirect emissions associated with the use of sold product are not included within the minimum boundaries of category 11 (use of sold products) though they can be significant in some cases).

Finally, some reporting standards based on the GHG Protocol (e.g., the *Science-Based Target initiative* [SBTi]) require the inclusion of only those emission sources that are within the minimum boundary requirements, meaning that optional emission sources must not be included.

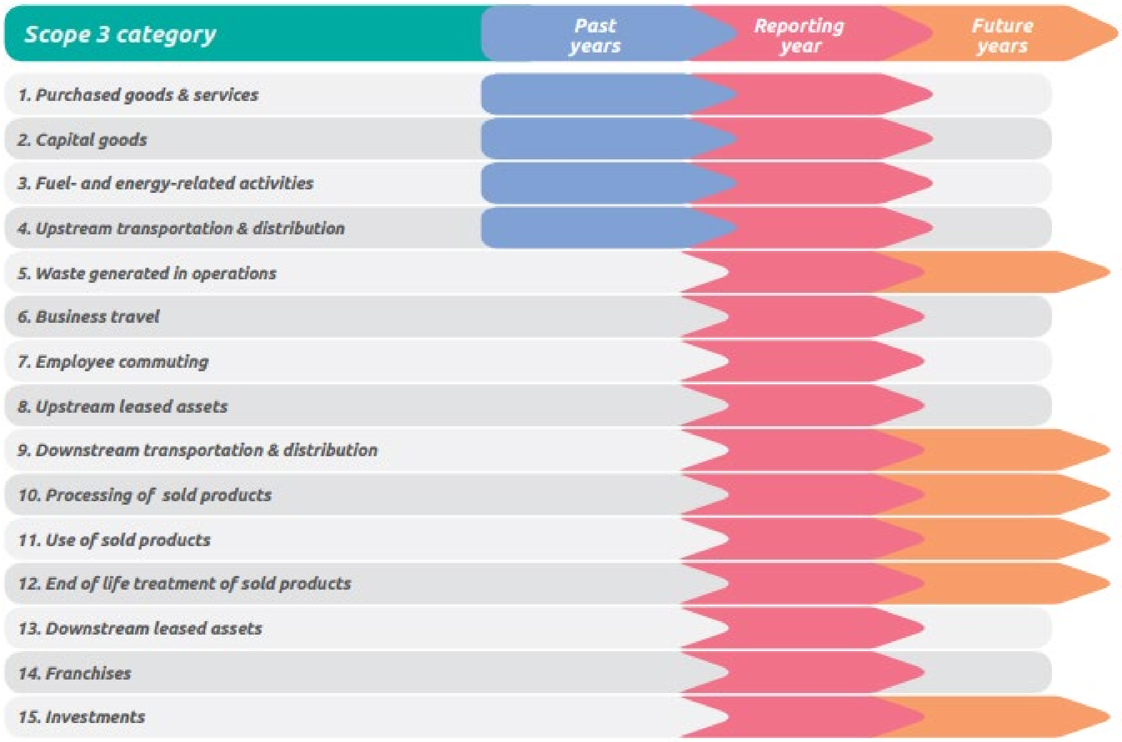
3.1.5 Temporality

The activities that generate GHGs and are included within the operational boundaries can occur **at different time frames**. All scope 1 and scope 2 emissions occur at the same time as the activity causing the emission (i.e., during the organization's reporting year). However, for some scope 3 categories, the emissions generated by an organization's activities may not be realized in the reporting year (see Figure 3-1). For example:

- Category 1 (Purchased goods and services): Emissions associated with the production of purchased goods and services are accounted for at the time of purchase, even though these emissions may have occurred years earlier.
- Category 5 (Waste generated in operations): Emissions from waste management generated by the organization are accounted for in the year the waste is generated. In practice, these emissions may not occur until several years after the waste is produced, when it actually breaks down and produces emissions that are released into the environment.
- Category 11 (Use of sold products): For products that consume energy during their use, the emissions associated with the energy consumed during their use phase are counted at the time of sale, even though these emissions have not yet occurred.

All of the scope 3 categories affected by a temporal difference between the activity and the emission are shown in Figure 3-1.

[8] Indeed, the use of life cycle inventory databases is recommended by the GHG Protocol to calculate GHG emissions, and these databases include emission sources that are outside the minimum boundaries.



Note: Reproduced from the *Scope 3 Standard* (Figure 5.3, p.33), by GHG Protocol, 2011a. https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf

Figure 3-1: Categories affected by a temporal difference between the activity and the actual emission associated with the activity

3.2 Boundaries in product LCA

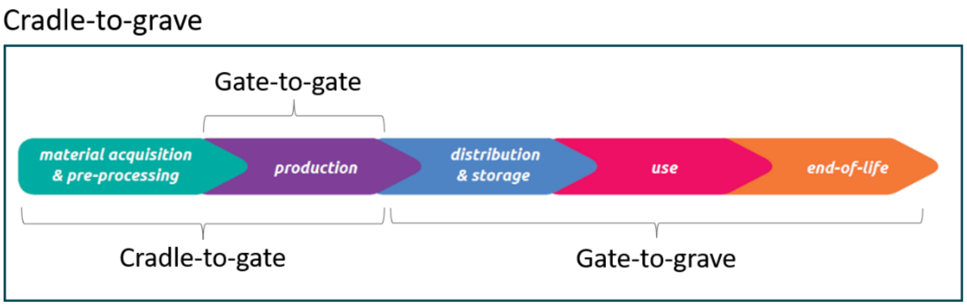
LCA uses the concept of *system boundaries* to define which activities are included within a study. The definition of system boundaries is flexible but must be aligned with the specific goals and scope of the LCA.

The main types of system boundaries are:

- *Cradle-to-gate*: including activities from raw material extraction to the manufacturing plant, before distribution to a subsequent consumer.
- *Cradle-to-grave*: including activities over the entire life cycle from raw material extraction through production, use, and final disposal.
- *Gate-to-grave*: including activities from the point of product distribution to the consumer up to its end-of-life.
- *Gate-to-gate*: including only a single activity or a group of activities within the life cycle (i.e., a part of the life cycle).

These boundaries are illustrated in Box 3-4.

Box 3-4: System boundaries in product LCA



Note: Reproduced and adapted from the *Product Standard* (Figure 7.5, p.41), by GHG Protocol, 2011b. https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf. System boundaries used in product LCA have been added to the original figure.

This figure shows the main stages of a product's life cycle, as presented in the *Product Standard* (GHG Protocol, 2011b). Here, the gate-to-gate boundary is illustrated by the production stage (i.e., a single activity), but it can refer to any activity or group of activities within the life cycle.

On the one hand, product LCA typically includes all **direct and indirect emissions from activities occurring across the product's life cycle**. More precisely, emissions from activities necessary to deliver the functional unit would be included (see section 1 for more information), regardless of whether the emissions are past, present, or future.

On the other hand, emissions from activities necessary for running the organization that markets the product but are not directly linked to the product's life cycle (hereafter referred to as "auxiliary activities") are usually excluded (e.g., employee commuting). However, the exact scope of included and excluded activities varies depending on the study's goal and scope, data availability, and methodological choices.

For instance, the cradle-to-gate carbon footprint of a chair would include:

- Emissions from the wood production needed to build the chair (e.g., forestry activities, transportation of the wood, sawmill).
- Emissions from the production of every additional intermediate product needed to manufacture the chair (e.g., screws, paint, glue).
- Emissions from the end-of-life treatment of the waste generated during the chair production.
- Emissions over the life cycle of the electricity needed by the equipment used on the chair assembly line.
- Emissions over the life cycle of all equipment present on the assembly line (e.g., machinery, tools), allocated to one chair, based on the total number of chairs that will be built in their lifetime (see section 4 for more information).

As noted above, auxiliary activities not directly linked to the product would typically be excluded from the study. In the example of the chair, these activities might be:

- Production of electricity and other sources of energy used by the supporting activities of the chair production company (e.g., heating and lighting of the buildings).
- Supporting activities within the chair production company (e.g., marketing, finances, R&D).
- Supporting activities outside the chair production company (e.g., insurance, banks).
- All activities relating to the employees (e.g., commuting, business travel, catering), even those related to employees who work directly on the assembly line.
- Activities related to capital goods over their life cycle, such as buildings (both the factory building and any employee workspace adjacent to the factory), or the company's vehicle fleet (see section 4 for more information).

Finally, in accordance with the *ISO 14044* standard, **certain activities and emission sources** (e.g., inputs, outputs) **may also be excluded** from the study if deemed **insignificant**. A defined *cut-off* criterion, such as X% of the input mass, X% of energy consumption, or X% of pollutant emissions, may be applied, allowing for the exclusion of activities that fall below these thresholds. The cut-off criteria must be described in the study report, and any exclusion must be justified.

3.3 Boundaries in organizational LCA

Although O-LCA is related to *ISO 14072* it generally defers to *ISO 14040/44* for boundary definition, except for certain specific methodological aspects.

O-LCA does not explicitly use the terms "organizational" and "operational boundaries," yet its methodological approach closely aligns with that of the GHG Protocol. *ISO 14072* adopts the same consolidation approaches used in the *Corporate Standard* (i.e., operational control, financial control, and equity share) to determine which facilities fall within the reporting organization's boundaries for GHG accounting.

Like the standards for product LCA, *ISO 14072* does not define specific scopes or emission categories and minimum boundaries. Instead, it stipulates that organizations must account for emissions over the entire life cycle of their activities. This means encompassing all inputs and outputs (i.e., cradle-to-grave) of the **activities associated with products or services sold during the reporting period**, as well as auxiliary activities necessary to run the organization. An example is illustrated in Box 3-5. Auxiliary activities comprise a wide variety of activities that can be: consumption of energy from sources that are not directly related to the product's manufacturing process (e.g., lighting or heating the offices), supporting activities taking place inside or outside the organization (e.g., marketing, insurance), activities related to the employees (e.g., commuting, professional travel), or even activities related to capital goods (e.g., buildings, machinery, infrastructure and vehicles).

The reporting organization must account for all upstream activities up to the organization's gate, as well as those occurring within the organization, before the distribution of sold products (i.e., cradle-to-gate boundaries). When the organization has no influence over the downstream activities in its supply chain (i.e., the use phase of its sold products, and the end-of-life of sold products), *ISO 14072* permits excluding these downstream activities from the study. It is common for raw materials and intermediate products, though the choice of cradle-to-gate boundaries instead of cradle-to-grave boundaries must be justified and aligned with the goal and scope of the study.

When accounting for the use phase of sold products, emissions should be included if the product consumes energy and generates emissions, either directly (e.g., an automobile directly generates emissions through fuel consumption) or indirectly (e.g., a garment indirectly uses energy through washing and drying, since it's the machines that consume energy, not the apparel itself).

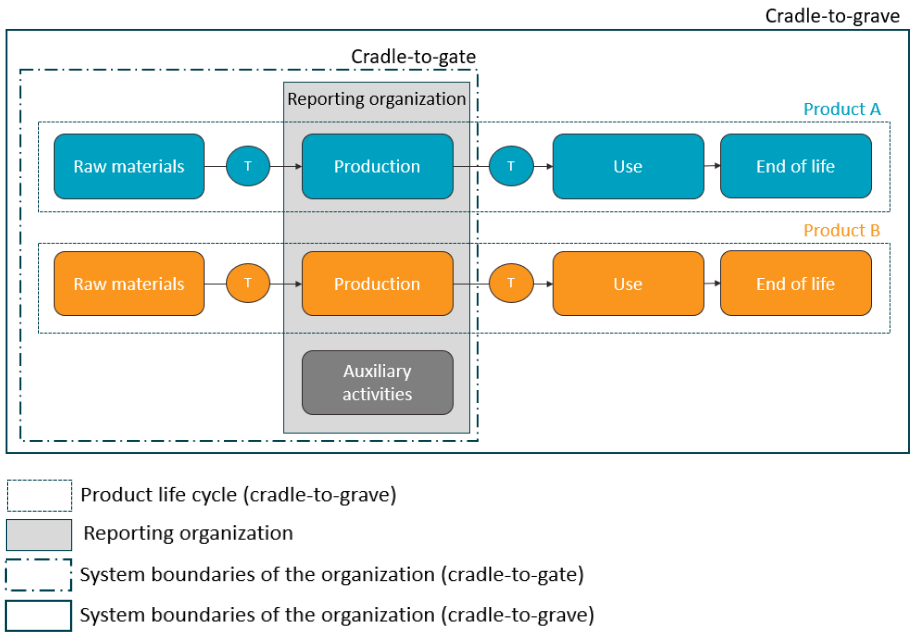
Two approaches can be applied to perform an O-LCA, based on *ISO 14072*:

- A *bottom-up approach*: This method involves conducting product-level cradle-to-grave LCAs for the products sold by the organization during the reporting year, weighing the results by the amount of each product, then adding them together with the emissions from auxiliary activities.
- A *top-down approach*: This method involves considering the organization as a whole, and adding both the upstream activities associated with the reporting organization's inputs (i.e., cradle-to-gate) and the downstream activities related to its outputs (i.e., gate-to-grave).

In O-LCA, the system boundaries include all direct and indirect emissions associated with the products' life cycle, as well as certain auxiliary activities. For example, supporting activities inside or outside the organization (e.g., marketing, insurance, banks) are usually excluded. This is because O-LCA encourages the use of data based on physical units (e.g., kilogram of material, kWh of electricity, kilometre travelled) rather than data based on financial units (e.g., per unit of expenditure).

Finally, attempting to account for all activities across the value chain can be complicated, and some auxiliary activities might be irrelevant. Thus, in accordance with *ISO 14044*, a *cut-off* criterion (based on mass, energy, or environmental significance) can be defined to determine which activities to include or exclude. The cut-off criteria must be described in the study report, and any excluded activities must be justified.

Box 3-5: Example of organizational system boundaries



Note: Reproduced and adapted from *ISO 14072:2024: Environmental management – Life cycle assessment – Requirement and guidance for organizational life cycle* (Figure 1, p.5), by ISO, 2024. https://www.iso.org/fr/standard/86265.html. Modifications have been made. This figure is also reproduced and adapted from *Guidance on Organizational Life Cycle Assessment* (Figure 8, p.51), by UNEP, 2015. https://www.lifecycleinitiative.org/wp-content/uploads/2015/04/o-lca_24.4.15-web.pdf.

This figure provides an example of system boundaries for a reporting organization. The organization is a manufacturing company operating one facility that manufactures and markets two products (A and B). The manufacturing of products A and B takes place within the company's boundaries.

According to *ISO 14072*, the company must apply cradle-to-grave boundaries. This means including emissions over the life cycles of products A and B (cradle-to-grave) and the organization's auxiliary activities. The manufacturing company could apply cradle-to-gate boundaries if it has no influence over the use phase and the end-of-life (i.e., waste treatment) of its sold products.

Auxiliary activities are presented here in a simplified way. In practice, these activities may occur both within the organization and externally, either upstream or downstream of the value chain.

3.4 Comparison of approaches – Boundaries

In the *Corporate Standard*, **system boundaries** are standardized through the introduction of two concepts: organizational boundaries and operational boundaries. Product LCA – *ISO 14040/44* – and organizational LCA – *ISO 14072* – use different terminology but introduce the same concept through the definition of system boundaries. Within the boundaries, the **GHG Protocol** (more precisely the *Corporate Standard* and the *Scope 3 Standard*) includes emissions from all the activities along the reporting organization's value chain, whether they are a direct (e.g., stationary combustion, mobile combustion) or an indirect (e.g., purchased raw materials, employee commuting, investments) consequence of the organization. **Product LCA** typically accounts for emissions from activities associated with the life cycle of the product or service sold by the organization, excluding emissions from auxiliary activities that are a consequence of the organization. **O-LCA** includes the same activities as product LCA but may also account for emissions from the organization's auxiliary activities. Auxiliary activities are those not directly linked to the product but that are mainly necessary for operating the organization (e.g., supporting activities, employee-related activities).

To define **organizational boundaries**, the *Corporate Standard* provides different consolidation approaches: equity share, operational control, and financial control. *ISO 14072* adopts the same consolidation approaches to determine which operations are within the reporting organization's system boundaries.

Under the GHG Protocol, **operational boundaries** are defined by classifying emissions into different scopes, separating direct from indirect emissions, and further dividing indirect emissions into categories. In product LCA, system boundaries may be set at various stages of the product life cycle (e.g., cradle-to-gate, cradle-to-grave). O-LCA boundaries fall between the GHG Protocol and product LCA in terms of system boundaries. They cover the cradle-to-grave of the organization, encompassing the life cycle of products sold by the organization, and the auxiliary activities necessary to run it.

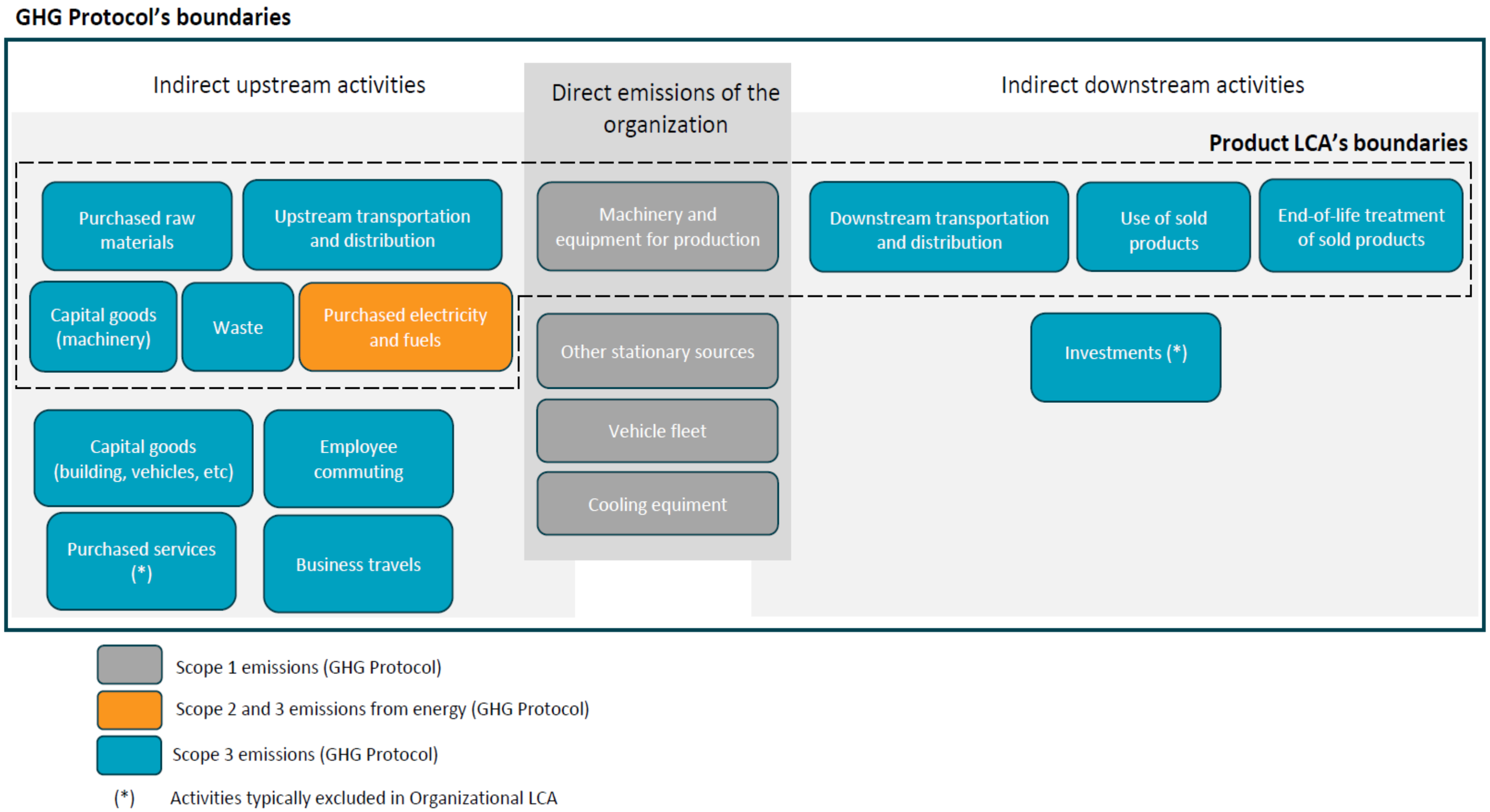
In practice, **some activities can be excluded from the boundaries**. Indeed, the *Corporate Standard* requires the reporting of direct emissions (scope 1) and indirect emissions from energy consumption (scope 2). Other indirect emissions (scope 3) are optional under the *Corporate Standard*. If they are included, it is permissible to exclude sources deemed irrelevant. Scope 3 emissions are only required under the *Scope 3 Standard*. When reporting scope 3 emissions, an organization may choose to include only the emission sources defined within the minimum boundaries, or it may go further by including optional sources for each scope 3 category. The ISO norms for product LCA and O-LCA allow for the definition of a *cut-off* criterion to exclude activities that fall below this threshold. In O-LCA specifically, cradle-to-gate boundaries may be applied instead of cradle-to-grave ones when the organization has no influence over the downstream activities of its sold products.

Finally, the **type of data** used to calculate emissions affects how boundaries are defined. Many indirect emissions can be calculated using physical data (e.g., emissions related to business travel or employee commuting are typically calculated with data expressed per person and kilometre travelled), while others are often calculated using financial data (e.g., emissions from purchased services are usually calculated with data expressed per unit of monetary expenditure on the service). The different types of data are further explained in *Technical Report 2*. Product LCAs rely mainly on physical data. O-LCA encourages the use of physical data, though it does not explicitly prohibit financial data. The *Scope 3 Standard* of the GHG Protocol more explicitly permits the use of financial data, though encouraging the use of physical data.

An illustration of boundaries definition under the GHG Protocol, product LCA and O-LCA is presented in Figure 3-2.

Regarding the **quantification of emissions**, the GHG Protocol and O-LCA treat emissions from the use phase of sold products differently. The *Scope 3 Calculation Guidance* requires accounting for direct emissions from the use of sold products, while accounting for indirect emissions is optional. By contrast, *ISO 14072* advocates for the inclusion of both direct and indirect emissions.

Finally, differences in system boundaries between the GHG Protocol and LCA can lead to varying implications for quantifying emissions. Product LCA usually focuses on quantifying a specific product or service (as reflected in the functional unit), whereas both the GHG Protocol and O-LCA account for the emissions of the whole reporting organization. As an organization typically provides several functions (e.g., selling different products or services, employing people), it may be necessary to partition the impacts between the different functions, especially when the organization uses primary data from suppliers, generates or uses recyclable materials. These implications are further discussed in section 9.



In this example, the reporting organization is a company that manufactures washing machines. It owns the production plant, the adjacent office spaces, the manufacturing machinery and a vehicle fleet for business travel.

The company conducts a cradle-to-grave product LCA (represented by ***Product LCA's boundaries*** *in the figure). This study generally accounts for emissions from all activities associated with the washing machine's life cycle, that are:*

Figure 3-2: Example of boundaries definition under the GHG Protocol, product LCA, and organizational LCA

- *Production of raw materials purchased from suppliers (**Purchased raw materials**);*
- *Transport of these materials to the company's production site (**Upstream transportation and distribution**);*
- *Production and end-of-life of machinery and equipment used for manufacturing, allocated per washing machine (**Capital goods (machinery)**);*
- *Assembly of the washing machine at the company's production site (**Machinery and equipment for production**), including electricity and fuel used to run the machinery and equipment (**Purchased electricity and fuels**);*
- *Waste from raw material production and assembly (**Waste**);*
- *Transport of the finished products to clients (**Downstream transportation and distribution**);*
- *Use of the washing machine during its lifetime (**Use of sold products**);*
- *End-of-life treatment of the washing machine (**End-of-life treatment of sold products**).*

*The company also prepares a GHG inventory in accordance with the GHG Protocol (represented by **GHG Protocol's boundaries** in the figure). This inventory includes scope 1, 2 and 3 emissions (i.e., all direct and indirect emissions associated with activities along the company's value chain).*

***Direct emissions** (i.e., scope 1, shown in **grey**) result from fuel combustion in production machinery, but also emissions from other sources that are not directly linked to the washing machine, such as fuel combustion in the vehicle fleet (**Vehicle fleet**), refrigerant leaks from cooling equipment (**Cooling equipment**), and fuel use in stationary sources that run the buildings (e.g., heaters) (**Other stationary sources**). Other life cycle emissions from these sources are indirect emissions.*

***Indirect emissions** (i.e. scope 3, shown in **blue**) result from **upstream** and **downstream** activities related to the company's value chain and are grouped into categories. Some relate directly to the washing machines' life cycle, such as the production of **Purchased raw materials** (category 1), **Upstream transportation and distribution** (category 4), **Use of sold products** (category 11), etc. Other relate to the company's auxiliary activities, like the production of other **Capital goods** (i.e., building, vehicles, cooling equipment, heaters, office equipment) (category 2), **Purchased services** (category 1), **Business travels** (category 6), and **Employee commuting** (category 7).*

*Indirect emissions also include energy-related emissions (shown in **orange**). Emissions from electricity production are reported as scope 2 emissions, while those from the rest of the electricity life cycle and fuel production consumed are included in scope 3 (category 3). Section 6 provides more details on electricity accounting.*

*Finally, an organizational LCA would ideally include the same emission sources as the GHG Protocol. However, as this approach advocates for the use of physical data, it often excludes activities typically quantified with financial data, such as **Purchased services** and **Investments** (market with * in the figure).*

Figure 3-2: Example of boundaries definition under the GHG Protocol, product LCA, and organizational LCA (continued)

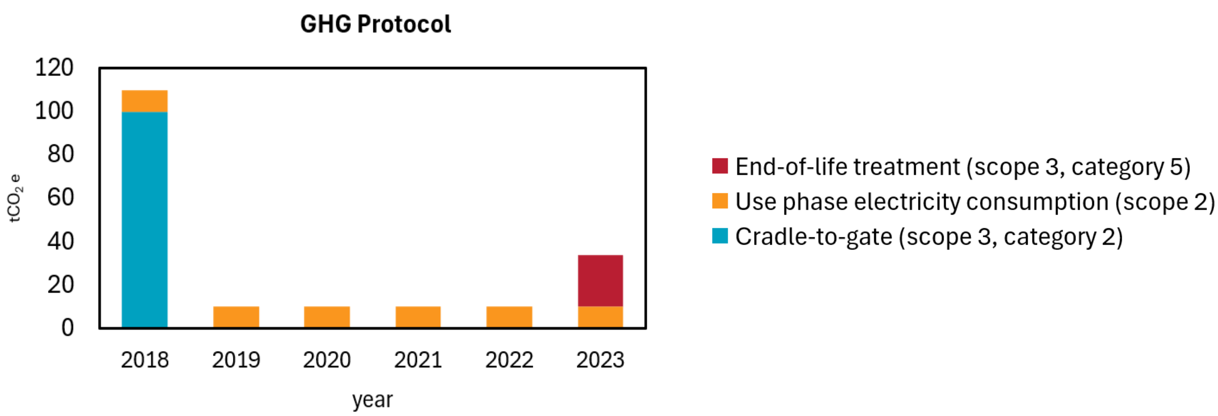
4. CAPITAL GOODS

Capital goods refer to company assets "used by the company to manufacture a product; provide a service; or sell, store, and deliver merchandise" (GHG Protocol, 2013a). These goods are fixed assets, property or equipment (e.g., manufacturing machines, buildings, facilities, and vehicles). They typically have extended lifespans and are used over several years, differentiating them from other purchased goods that are typically purchased and consumed within the same year.

4.1 Capital goods in the GHG Protocol

Although a capital good may be used over several reporting years, it is recommended that the emissions associated with its **production** be reported in the year that the good is **acquired** by the reporting organization, and **not to "depreciate, discount, or amortize [...] over time"** (GHG Protocol, 2011a). The cradle-to-gate emissions of the good are reported in scope 3, category 2 (Capital goods). Emissions associated with its use and end-of-life treatment will be reported in the year(s) that they occur, and as part of other scopes/categories[9].

For example, the emissions associated with a piece of equipment purchased by the reporting organization in 2018, used for five years and then decommissioned and sent to a landfill in 2023, would be accounted for as shown in Figure 4-1. The cradle-to-gate emissions associated with the manufacturing of the equipment are accounted for in 2018, the year of purchase (reported in scope 3 category 2). The emissions associated with the electricity used to run the equipment are reported in the years that the electricity is consumed (reported in scope 2). If the equipment ran on fuel, emissions from fuel combustion would be reported in scope 1. Finally, the emissions from the end-of-life of the equipment are reported in the year it is sent to a landfill — 2023 (reported in scope 3, category 5 [Waste generated in operation]).



Note: Emission values are shown in tonnes of CO_2 equivalent (tCO_2e).

Figure 4-1: Treatment of emissions associated with capital goods' life cycle in the GHG Protocol

[9] See section 5.5 of the *Corporate Value Chain (Scope 3) Standard* (GHG Protocol, 2011) and Section 2 of the *Technical Guidance for Calculating Scope 3 Emissions* (GHG Protocol, 2013a).

Since the lifespan of capital goods can be uncertain, allocating all upstream emissions to the year of purchase ensures they are fully accounted for. However, when capital goods with large cradle-to-gate emissions are purchased only periodically, this can lead to significant fluctuations in an organization's GHG inventory results from year to year, which can complicate the tracking of emissions over time and its consistency.

Capital goods within the value chain (i.e., those not directly purchased by the reporting organization) may be relevant to several scope 3 categories. For instance, infrastructure is needed to support various activities: manufacturing plants are needed to produce purchased goods (category 1), and vehicles are necessary to transport those goods (category 4), among others. However, capital goods are only included within the minimum boundaries of purchased goods and services (category 1). Their inclusion is considered optional for all other scope 3 categories.

For purchased goods and services (category 1), the minimum boundaries include cradle-to-gate emissions, which should account for the infrastructure associated with a product (e.g., the facility where it is manufactured). When organizations calculate emission factors using primary data, the GHG Protocol recommends following the *Product Standard*, which neither requires nor provides guidance on including capital goods. Conversely, when secondary data are used, the GHG Protocol refers to several life cycle inventory (LCI) databases that do include infrastructure, both for purchased goods and for other scope 3 categories (e.g., for transportation, where vehicle production is typically included in the emission factors). Primary and secondary data are further explained in *Technical Report 2*.

Consequently, a significant gap exists in GHG Protocol guidance regarding the consistent treatment of capital goods embedded in other scope 3 categories, apart from category 2 (Capital goods) itself.

4.2 Capital goods in LCA

4.2.1 Capital goods in product LCA

According to *ISO 14040*, emissions associated with the **production, maintenance, and decommissioning of capital goods** should be included in the LCA if they are aligned with the goal and scope. However, capital goods are typically used to manufacture several products or provide several services. In LCA, any system (e.g., machinery, plant) that provides multiple outputs is **typically partitioned into each output**. This involves allocating inputs (i.e., materials, services, energy) to the product or service under study.

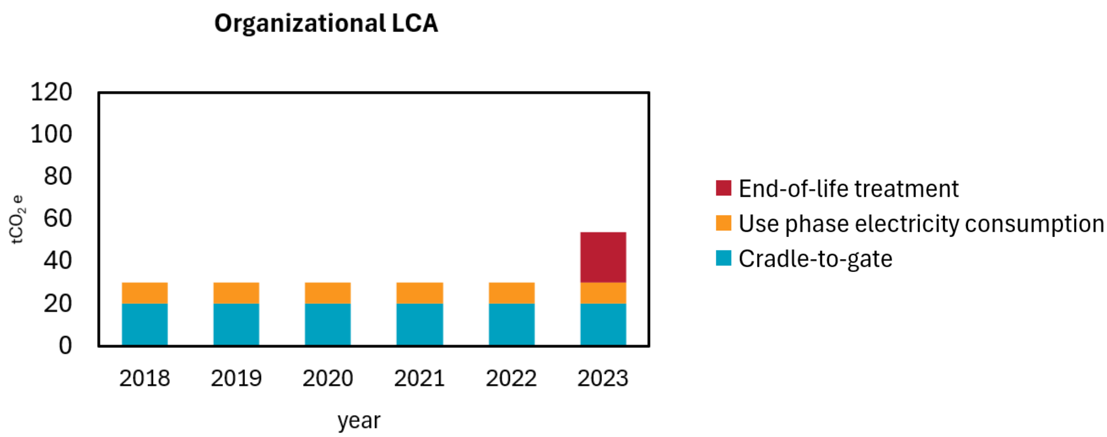
The production of capital goods is typically distributed across all the products they manufacture over their useful lifetime. Common allocation methods involve attributing impacts based on the total number of units the good can produce, the total mass produced, or the time each product uses the equipment. However, since the total lifespan or total products made over the lifetime of a piece of equipment is often unknown, this can introduce uncertainty into the calculation if assumptions about the lifespan must be made.

In practice, manufacturing machines are often included in LCI databases, whereas other capital goods (e.g., buildings) are often omitted from studies, even though they should be included. Moreover, capital goods in LCI databases are poorly modelled, with outdated datasets.

4.2.2 Capital goods in organizational LCA

ISO 14072 stipulates that emissions associated with the **production** of capital goods **should be amortized over their years of use**. Thus, O-LCA is aligned with product LCA. However, in O-LCA, the allocation is based on the temporality of the reporting unit (see section 2.2.2 for more information) over the entire lifetime of the piece of equipment.

Taking the previous example of the piece of equipment purchased in 2018 and sent to a landfill in 2023, and using a reporting unit of "one year of business activities", the emissions associated with the manufacturing of the equipment would be amortized equally across the five years of use, as shown in **Erreur! Source du renvoi introuvable.**. Emissions associated with electricity consumption are accounted for in the year the electricity is consumed, while emissions associated with end-of-life treatment are accounted for in the year the treatment occurs, as in the GHG Protocol.



Note: Emission values are shown in tonnes of CO_2 equivalent (tCO_2e).

Figure 4-2: Treatment of emissions associated with capital goods' life cycle in organizational LCA

4.3 Comparison of approaches – Capital goods

While both approaches account for emissions across the full life cycle of capital goods (i.e., manufacturing, use, and end-of-life), the allocation of manufacturing impacts differs between the methods.

On the one hand, the **GHG Protocol** recommends not amortizing these emissions, meaning that all emissions associated with the production of a capital good should be accounted for in the reporting period during which it is acquired. This approach has the advantage of being simple to apply and of avoiding uncertainties related to the lifespan of capital goods. However, it can also lead to emission spikes, particularly when capital goods acquisition is not recurring.

On the other hand, the methods used in LCA are based on amortization. **Product LCA**'s approach equally allocates emissions between products manufactured or services rendered, depending on the functional unit. In **O-LCA**, the manufacturing of capital goods is also amortized based on the temporality of the reporting unit, typically one year.

5. GREENHOUSE GASES AND INDICATORS

Climate change originates from an imbalance between incoming solar energy absorbed by the Earth and the outgoing infrared radiation emitted by the Earth into the atmosphere. This imbalance is called **radiative forcing** (expressed in W/m^2). Radiative forcing is caused by different mechanisms, including the *greenhouse gas effect*. The greenhouse effect describes how certain atmospheric gases absorb and re-emit infrared radiation from Earth's surface, instead of allowing it to escape into space. These gases, called *greenhouse gases* (GHGs), trap heat and warm the Earth's surface, leading to a rise in temperature (SCORE LCA, 2024).

According to the Intergovernmental Panel on Climate Change (IPCC), a large share of emissions from human activities (i.e., anthropogenic emissions) results from the combustion of fossil fuels (81% to 91%), though another significant source of GHG emissions is land use and land use change (9% to 19%) (Forster et al., 2023). Land use and land use change (LULUC) impacts are further discussed in section 8.

While GHGs are a significant driver of radiative forcing, other mechanisms affect climate change. These mechanisms are:

- *Albedo*: Albedo measures the fraction of solar radiation reflected by Earth's surfaces into space. This reflection reduces Earth's energy absorption, creating a cooling effect and a temperature decrease. In practice, albedo effects are generally not quantified in LCA.
- *Air pollutants*: Emissions of certain air pollutants contribute to radiative forcing, even though they are not GHGs. These include aerosol agents (also called *particulate matter*), which are sulphate, nitrate, ammonium, carbonaceous aerosols (e.g., black carbon, organic carbon), mineral dust and sea spray (Szopa et al., 2023). These agents can either have a cooling or a warming effect. For example, black carbon is a fine particle produced through the incomplete combustion of biomass and fossil fuels. This particle has a persistence time of a few days in the atmosphere, but its ability to absorb sunlight increases surface warming in areas where it accumulates. On the contrary, aerosols like sulphur oxides or organic carbon scatter solar radiation, therefore cooling the climate. Unlike gases such as carbon dioxide and methane, which have global impacts, aerosols primarily affect climate on a regional scale and remain in the atmosphere for only a few hours to several months. Their spatial variability makes it challenging to quantify their impact in LCA in practical applications.
- *Contrails*: Contrails result from the condensation of water vapour around soot particles released through aviation fuel combustion, when the air is cold and humid. Some contrails fade in a few minutes, while others can persist in the atmosphere and then form cirrus clouds. The latter are similar to thin clouds and may have a warming effect comparable to that of CO_2 emissions (IPCC, 1999; Lee et al., 2021).

5.1 Greenhouse gases and indicators in the GHG Protocol

The GHG Protocol requires the quantification of emissions from the **seven GHGs covered in the Kyoto Protocol**: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). These GHGs must be included in scope 1, 2 and 3 emissions calculations to ensure compliance with both the *Corporate Standard* and the *Scope 3 Standard*. These GHGs affect climate change through their radiative forcing.

In the atmosphere, GHGs have different radiative forcing intensities and different lifespans. For example, methane is a major short-lived greenhouse gas with a high immediate impact but a short atmospheric persistence time (around 12 years), compared to carbon dioxide, which has a long lifetime (over 100 years) (SCORE LCA, 2024). To compare the effects of different greenhouse gases on climate change, GHG emissions are converted to a **common unit**, that is the *CO_2 equivalent* (CO_2eq).

In the GHG Protocol, this conversion is performed using a metric that is the *Global Warming Potential* (GWP), introduced by the IPCC. More precisely, the GHG Protocol requires the use of **GWP100** (GHG Protocol, 2013b). This means that climate change impacts are evaluated over a 100-year period following the emission. Further details about the GWP are given in section 5.2. The GWP was first introduced in the IPCC's *First Assessment Report* (IPCC, 1990), but these values for different GHGs are periodically reassessed. To date, the most recent report is the *Sixth Assessment Report* (IPCC, 2023).

The GHG Protocol recommends using GWP100 values from the latest IPCC Assessment Report, though earlier reports may also be used. However, GWP values from the same Assessment Report must be used for any one inventory. If a GWP is not disclosed in the chosen Assessment Report, the most recent GWP for that GHG must be used (GHG Protocol, 2013b).

Finally, the other mechanisms that affect climate change (e.g., albedo, contrails) are not accounted for in the GHG Protocol.

5.2 Greenhouse gases and indicators in LCA

Product LCA and O-LCA provide a more comprehensive evaluation of GHG emissions compared to the GHG Protocol, accounting for **emissions of most GHGs, including those beyond the scope of the GHG Protocol** (Levasseur et al.,2016; UNEP, 2016; GHG Protocol, 2024)**,** specifically:

- Carbon monoxide (CO);
- Hydrochlorofluorocarbons (HCFCs);
- Chlorofluorocarbons (CFCs);
- Other fluorinated compounds (trifluoromethylsulfur pentafluoride, sulfuryl fluoride, etc.);
- Chlorocarbons and hydrochlorocarbons (methyl chloroform, carbon tetrachloride, etc.);
- Bromocarbons, hydrobromocarbons and halons (halon-1201, methyl bromide, etc.);
- Halogenated alcohols, ethers, furans, aldehydes and ketones (perfluoropolymethylisopropyl ether, pentafluorodimethyl ether, etc.).

Most of these substances are GHGs that exert radiative forcing once emitted, but some are also *precursors* to GHGs. Precursors are substances that undergo chemical reactions in the atmosphere and lead to the formation of GHGs. For example, CO reacts with hydroxyl radical, a key atmospheric oxidant, to oxidize into CO_2.

As noted in section 5.1, GHGs have different lifespans and climate effects. In LCA, GHG emissions can be calculated in CO_2 equivalent using two different metrics (SCORE LCA, 2024):

- The *Global Warming Potential* (GWP): The GWP assesses the **radiative forcing potential of a gas emitted** into the atmosphere from the time of emission over a certain period, relative to that of CO_2. It is therefore an integrative measure, assessing impact **over a defined time frame rather than at a specific time** (IPCC, 1990).
- The *Global Temperature change Potential* (GTP): The GTP assesses the **global average**

temperature increase at a certain time point in the future caused by a gas emission into the atmosphere, relative to the temperature increase that would be caused by an equivalent mass of CO_2 (Shine et al., 2005). Compared to GWP, GTP is an **instantaneous metric**.

The GWP can be assessed over different time frames which can be 20, 100 or 500 years (respectively called *GWP20*, *GWP100* and *GWP500*), and GTP over 20, 50, or 100 years (respectively called *GTP20*, *GTP50* and *GTP100*). These values for different GHGs are periodically reassessed in each new IPCC Assessment Report to reflect the most accurate and up-to-date representation of climate science. These metrics quantify the marginal effect of emitting one additional kilogram of GHG in the atmosphere. It is based on changes in atmospheric concentration of this gas since the pre-industrial period (IPCC, 1990). Therefore, changes in atmospheric GHG concentrations over time will alter the GWP and GTP values.

Among the LCA community, the UNEP Life Cycle Initiative highlights that using a single metric cannot fully capture the complexity of climate change. Indeed, a single metric measured in total CO_2-equivalent prevents the differentiation of impacts of gases with short-term lifetimes (i.e., with a lifetime of decades, like CH_4, HFCs, etc.) from the ones with long-term lifetimes (i.e., with a lifetime of centuries, like CO_2, CFCs, etc.), therefore affecting the ability to make informed decisions. In this context, the use of **two metrics** is advocated in LCA:

- The **GWP100** to evaluate **short-term impacts** on climate change (i.e., in the next decades);
- The **GTP100** to evaluate **long-term impacts** on climate change (i.e., in the next centuries). Even if GTP is an instantaneous metric, compared to other common integrative metrics like GWP100, it is recommended in the literature for representing long-term impacts, as the IPCC does not recommend modelling GWP for a long-term horizon due to high uncertainty. GTP is an appropriate proxy as its values are comparable to those of a GWP calculated over several centuries (Levasseur et al., 2016; UNEP, 2016; SCORE LCA, 2024).

A 100-year time horizon captures most of the atmospheric lifetime of CH_4, which is the most significant short-lived GHG after CO_2. However, **the chosen time horizon can greatly influence a study's results**. For example, GHGs with a short lifetime, such as CH_4, will have more weight in the results with a short time horizon, such as 20 years, while their effects will be negligible with a very long time horizon, like 500 years. To ensure thorough decision-making and better understand short-term effects, LCA practitioners should use the **GWP20** in sensitivity analyses when relevant, especially when CH_4 emissions are significant (Levasseur et al., 2016; UNEP, 2016).

When conducting an LCA, a *life cycle impact assessment* (LCIA) method must be selected to evaluate climate change impacts. In practice, activities are modelled using LCA software tools (e.g., SimaPro [Pré Sustainability, 2026], openLCA [GreenDelta, 2026]) that include LCI databases. These databases provide pre-modelled processes containing an activity's inputs and outputs (e.g., materials, waste, emissions). This inventory is then converted into environmental impact indicators using *characterization factors*. However, since there is no single widely accepted LCIA method, practitioners can choose among several LCIA methods, each with its own set of characterization factors.

For the climate change category, these factors may be the GWP derived from the IPCC model. All LCIA methods include at least the GWP100 metric, but its values are not always sourced from the most recent IPCC report. For example, Impact World + Version 2.1 (Bulle et al., 2019) and the Environmental Footprint (EF) 3.1 method (Andreasi Bassi et al., 2023) both use GWP100 values from the *Sixth Assessment Report*

(Forster et al., 2023), whereas ReciPe 2016 values are from the *Fifth Assessment Report* (Huijbregts et al., 2016; IPCC, 2013), and TRACI[10] 2.1 from the *Fourth Assessment Report* (Bare, 2012; Solomon et al., 2011). Additionally, only a few methods enable the quantification of long-term emissions. As of this writing, IMPACT World+ is the only LCIA method using GTP100 to evaluate long-term impacts. However, the latest Assessment Report can also be used to evaluate climate change impacts using the most up-to-date GTP100 values, to assess both short- and long-term impacts.

LCIA methods can also account for other mechanisms influencing climate change. However, these are rarely included in practice because of the difficulty of understanding and quantifying them, caused by their spatial heterogeneity.

Finally, LCIA methods assess multiple potential environmental impacts beyond climate change (e.g., acidification, particulate matter formation, water scarcity). This multi-indicator approach is important, as focusing solely on climate change impacts could solve one issue while inadvertently causing another, thus shifting environmental burdens. This consequence is called *burden-shifting*. For example, a company in a hydro-powered region that switches its fleet from internal combustion engines to electric vehicles effectively reduces GHG emissions by using cleaner electricity and avoiding fossil fuel combustion. However, this shift increases impacts on mineral resource depletion (i.e., for producing the vehicle) and land occupation (i.e., for hydropower reservoirs), highlighting the trade-offs between environmental burdens.

5.3 Comparison of approaches – Greenhouse gases and indicators

The GHG Protocol, product LCA and O-LCA differ in their scope for quantifying GHG emissions. The main differences lie in the **types of GHGs considered**, the metrics used to quantify climate change impacts, the climate change mechanisms that can be accounted for, and the environmental impact indicators evaluated.

The GHG Protocol requires quantifying emissions from the seven GHGs covered in the Kyoto Protocol. These GHGs account for the vast majority of radiative forcing from human activities. Product LCA and O-LCA provide a more comprehensive view, enabling the assessment of additional GHGs and their precursors. However, these generally have a limited impact on a system's total emissions and are not significant, but exceptions can occur in certain sectors or under specific circumstances, particularly at the product level.

Regarding **metrics for quantifying climate change impacts**, the GHG Protocol mandates the use of GWP100. By contrast, two distinct metrics are typically used in LCA to distinguish between short- and long-term impacts: GWP100 is recommended for evaluating short-term impacts (complemented by GWP20 in sensitivity analyses where relevant), and GTP100 for long-term impact assessment.

Apart from GHG emissions, the GHG Protocol does not account for **other mechanisms that affect climate change**. In LCA, the effects of albedo and contrails on climate change are generally not quantified. The effects of air pollutants on climate change are included in some LCIA methods, but are difficult to quantify due to their spatial heterogeneity.

Finally, a key distinction between the GHG Protocol and LCA lies in the **scope of the environmental**

[10] TRACI stands for "Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts".

indicators evaluated. While the GHG Protocol exclusively addresses climate change impacts through GHG accounting, LCA adopts a broader perspective by assessing multiple potential environmental indicators, therefore highlighting potential burden shifting.

6. ELECTRICITY ACCOUNTING

As mentioned in section 3, emissions associated with purchased electricity, heat, steam, and cooling (hereinafter referred to as "electricity"[11]) are treated in a specific way under the GHG Protocol. This treatment first addresses how the life cycle emissions of these energy carriers are disaggregated and reported across different categories. Second, emissions from these sources are subject to specific accounting methods, including consideration of market instruments linked to energy purchases.

6.1 Electricity accounting in the GHG Protocol

6.1.1 Disaggregation and reporting

Because electricity purchases are often a significant source of indirect emissions and a key lever for decarbonization, the GHG Protocol introduced scope 2 to require their inclusion in corporate GHG inventories, beginning with the publication of the *Corporate Standard* in 2001.

However, **scope 2** covers only part of the life cycle emissions from purchased electricity, accounting only for **emissions from fuel combustion at the power generation site**. Other **life cycle emissions**, such as fuel production and transmission losses, are reported under **category 3 of scope 3** (Other indirect emissions from energy [not included in scopes 1 or 2]).

Renewable electricity typically has a scope 2 emission factor of zero, as it does not involve fuel combustion during generation (see section 1.2 of *Technical Report 2* for more information about emission factors). All its life cycle emissions are instead reflected in its scope 3 emission factor. In contrast, thermal power has a higher scope 2 emission factor than scope 3, since combustion is the main contributor to its life cycle emissions.

The GHG Protocol further disaggregates category 3 of scope 3 into three activity types related to electricity purchases, described in Table 6-1.

[11] This section refers to "electricity" for simplicity, as it is the most common energy type in scope 2, though steam, heat, and cooling are also included.

Table 6-1: Activities included in category 3

Activity	Description	Applicability
Activity 1: Upstream emissions of purchased electricity	Extraction, production, and transportation of fuels consumed in the generation of electricity that is consumed by the reporting organization	Applicable to end users of electricity
Activity 2: Transmission and distribution (T&D) losses	Generation (upstream activities and combustion) of electricity, steam, heating, and cooling that is consumed (i.e., lost) in a T&D system – reported by end user	Applicable to end users of electricity
Activity 3: Generation of purchased electricity that is sold to end users	Generation (upstream activities and combustion) of electricity that is purchased by the reporting organization and sold to end users – reported by utility company or energy retailer	Applicable to utility companies and energy retailers

Note: Reproduced from *Technical Guidance for Calculating Scope 3 Emissions* (Table 3.1, p.39), by GHG Protocol, 2013a. https://ghgprotocol.org/sites/default/files/standards/Scope3_Calculation_Guidance_0.pdf

Figure 6-1 illustrates emissions that are part of scope 2 and minimum boundaries of scope 3, category 3, specifically for energy purchases from end users.

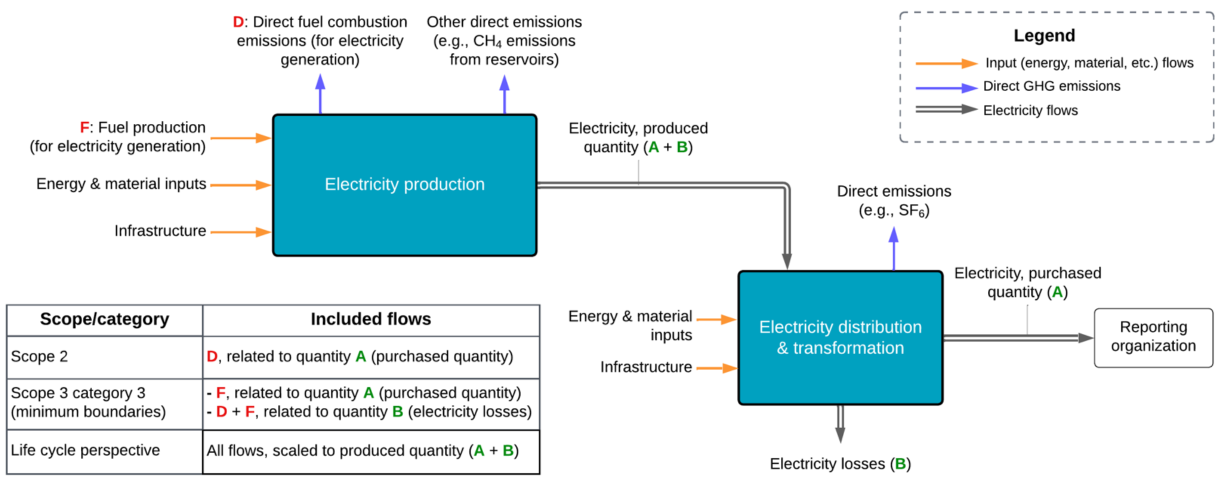


Figure 6-1: Disaggregation of emissions across scopes and categories for end users of electricity

In general, only Activities 1 and 2 from Table 6-1 apply to organizations purchasing electricity, since Activity 3 is specific to electricity distributors. Note that the GHG Protocol defines “upstream activities” primarily as the production (i.e., cradle-to-gate) of fuels. However, organizations may choose to include additional upstream emissions, such as those associated with infrastructure construction. Therefore, Activity 1 covers all life cycle emissions of electricity except combustion at generation (reported in scope 2) and transmission and distribution (T&D) losses (covered in Activity 2). Activity 2 accounts for all emissions associated with electricity lost during T&D, including combustion emissions. However, organizations are not required to disaggregate emissions by the activities listed in Table 6-1; they may simply report total emissions under category 3 of scope 3.

Disaggregating electricity emissions between scope 2 and scope 3 can pose challenges. While scope 2 emission factors are often readily available from national inventory reports, life cycle-based emission factors, such as those from LCI databases, are rarely aligned with the GHG Protocol's boundary definitions. They typically include combustion emissions (scope 2), which can lead to double-counting unless the organization manually removes them from the emission factors. As of this writing, ecoinvent (Wernet et al., 2016) is the only LCI database to disaggregate electricity data between scopes 2 and 3[12].

6.1.2 Calculation method

Two methods can be used for calculating emissions from electricity purchases: the *location-based method* and the *market-based method*.

On the one hand, the **location-based method** uses average emission factors from the electricity grid in a defined geographic area (local, sub-national, or national). The only exception is when the organization is directly connected to its electricity provider, in which case the provider-specific emission factor can be used.

On the other hand, the **market-based method** allows organizations to use emission factors from their specific electricity supplier, provided the purchase is backed by an energy attribute certificate. Under this method, the organization applies the emission factor associated with the instrument (e.g., *Renewable Energy Certificates* (RECs) in the United States or *Guarantees of Origin* in the European Union) provided the instrument meets certain quality criteria. These criteria generally ensure temporal and geographic correlation with the organization's context and require exclusivity to avoid double-counting[13]. A key component of the market-based approach is the use of the residual mix for any electricity purchases not covered by certificates, specified-source contracts, or supplier-specific data. This helps prevent double-counting of renewable claims made through contractual instruments.

Regarding method selection, organizations operating in any market where energy attribute certificates exist must report emissions using both the market-based and location-based methods, for the entire organization. This means that once an organization operates in such a market, it must report both location-based and market-based electricity-related emissions. Conversely, if the organization operates solely in markets where these instruments are not available, it may report only location-based emissions. The GHG Protocol provides a hierarchy of emission factor sources for both methods[14].

Purchases of steam, heat, and cooling may also be supported by contractual instruments that provide emission information (e.g., *green heat* certificates, where heat produced from biogenic sources is injected into heating networks). These purchases follow the same rules as electricity, meaning organizations must report two values when operating in markets that offer these instruments[15].

While the GHG Protocol *Scope 2 Guidance* established a market-based method for electricity, steam, heat, and cooling, no definitive guidance currently exists for applying a similar approach to renewable natural

[12] It should be noted that ecoinvent interprets scope 2 as all direct emissions on the electricity generation site (i.e., direct emissions of the electricity producer). For example, its hydroelectricity scope 2 emission factor includes GHG emissions from flooding and vegetation decomposition in reservoirs.

[13] Scope 2 Quality Criteria are listed in Table 7.1 of the *Scope 2 Guidance* (GHG Protocol, 2015b).

[14] See tables 6.2 and 6.3 of the *Scope 2 Guidance* (GHG Protocol, 2015b).

[15] In the case of a direct line between the supplier and organization, these two values may be the same.

gas (RNG) in scope 1. An annex to the draft of the *Land Sector and Removals Guidance* (GHG Protocol, 2022b) proposes that RNG certificates cannot be used to adjust scope 1 emissions from gas delivered via a common carrier pipeline. However, this annex will be withdrawn from the final version, as the GHG Protocol determined that the question requires further consideration (GHG Protocol, 2023). As stated, extending the market-based method beyond scope 2 "requires a broader process to determine whether it is appropriate for other sectors, and if so what rules and procedures are needed" (GHG Protocol, 2023).

6.2 Electricity accounting in LCA

In LCA, both at the product and organizational levels, the full life cycle emissions of electricity are considered and attributed to the consuming system.

In LCA, the **location-based approach** generally prevails. This method is commonly recommended (if not explicitly required) by most LCA-related normative frameworks. *ISO 14040/44* does not require it, but states that "when determining the elementary flows associated with production, the actual production mix should be used whenever possible [...]" (ISO, 2006; ISO, 2022).

However, the consideration of specific attributes of purchased energy or products, particularly when backed by economic instruments, is also a common practice in the LCA community. In fact, consequential modelling[16], which seeks to capture the impact of decisions through substitution logic and economic signalling, is conceptually aligned with the market-based approach. Even in attributional LCA[17], *book and claim* type certificates[18] have historically been considered valid under certain frameworks and in specific sectors (e.g., when electricity purchases are backed by energy attribute certificates). This approach is accepted in certain standards, such as the *Product Environmental Footprint* (PEF) (Damiani et al., 2022), the *ISO 14067* standard (ISO, 2018), and sector-specific *Product Category Rules* (PCRs).

6.3 Comparison of approaches – Electricity accounting

The main difference between the two approaches concerns how life cycle emissions from electricity are **disaggregated across different scopes and categories**. In **product** and **organizational LCA**, all life cycle emissions associated with energy are attributed directly to the system that consumes it. In contrast, the **GHG Protocol** separates these emissions: scope 2 covers only emissions from fuel combustion at the point of electricity generation, while the remaining life cycle emissions (e.g., upstream fuel production, infrastructure, and transmission losses) are reported under category 3 of scope 3.

As a result, organizations following the GHG Protocol have historically reported only scope 2 emissions, since scope 3 reporting is optional under the *Corporate Standard*. This has often resulted in a less comprehensive picture of electricity-related emissions, especially for renewables. Furthermore, data based on the LCA approach (e.g., LCI databases) are not structured in alignment with the GHG Protocol's

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[16] Consequential LCA enables to quantify the environmental consequences of a decision (e.g., the development of new technologies).

[17] Attributional LCA enables to quantify the environmental impact of an average product or a service by modelling the activities along its life cycle.

[18] In a *book and claim* system, sustainability certificates issued by an independent body based on verified upstream flows can be freely traded independently of the physical goods, with mass balance maintained only at the market level.

reporting requirements, leading to inconsistencies when used in that context.

In terms of calculation methods, there is no fundamental difference between the two approaches. The practice of accounting for the attributes of a purchased product or energy source, when backed by economic instruments, is well established in LCA, whether it concerns electricity or other certified products (e.g., Forest Stewardship Council-certified wood). However, the location-based approach remains predominant and is generally recommended, if not required, by most LCA-related standards and frameworks. Therefore, while the methods endorsed by the GHG Protocol are not inherently different from those used in LCA, the GHG Protocol has played a key role in formalizing and standardizing the market-based approach.

7. BIOGENIC CARBON

Biogenic carbon refers to carbon atoms (typically in the form of CO_2, CH_4 or CO) that have been transferred from the atmosphere to the biosphere through biological processes (SCORE LCA, 2024; GHG Protocol, 2022a). These biogenic carbon atoms and their resulting compounds are identical to those from fossil sources, and GHG emissions from biogenic sources will have the same effect on radiative forcing as those from fossil and geologic sources.

The main distinction between *biogenic* and *fossil carbon* is the timescales of their respective carbon cycles. **Biogenic carbon** is part of a relatively **short-term cycle**, typically spanning years to decades, in which CO_2 absorbed from the atmosphere during biomass growth through photosynthesis is eventually returned through decomposition or combustion (SCORE LCA, 2024). In contrast, **fossil carbon** originates from biological material that was sequestered over **geological timescales**, from centuries to millions of years ago, and has remained outside the active carbon cycle since then (SCORE LCA, 2024). As a result, the CO_2 removal associated with fossil carbon is not accounted for in GHG accounting, as it is considered geologically removed and unrelated to contemporary human activity. Conversely, for bio-based products, the removal of atmospheric CO_2 through photosynthesis is generally induced by human activities and is therefore attributed to these products. This distinction between biogenic and fossil carbon has led to the development of specialized accounting methods to characterize and report biogenic carbon emissions and removals arising from the life cycle of bio-based products.

7.1 Biogenic carbon in the GHG Protocol

The requirements and guidance for biogenic carbon accounting within the GHG Protocol are spread across four documents: the *Corporate Standard*, the *Scope 3 Standard*, the *Agricultural Guidance* (GHG Protocol, 2014), and the *Land Sector and Removals Standard* (GHG Protocol, 2026). The following subsections first outline the prevailing recommendations and requirements of the GHG Protocol, as set out in the first three cited documents, and then provide an overview of the new requirements of the *Land Sector and Removals Standard.*

7.1.1 Prevailing recommendations and requirements

The *Corporate Standard* requires that direct **CO_2 emissions** from biologically sequestered carbon (e.g., those from burning biomass or biofuels) be **reported**, but **separately from the scopes** (i.e., from the GHG inventory results). The *Scope 3 Standard* expands on this by also requiring the separate reporting of indirect biogenic CO_2 emissions. In practice, however, reporting indirect biogenic CO_2 emissions is significantly more complex. As a result, most organizations limit their separate reporting to direct biogenic CO_2 emissions (i.e., in scope 1). Indirect biogenic CO_2 emissions are often either omitted entirely, when they are not included in emission factors, or reported within the scopes if already embedded in emission factors, rather than being disclosed separately as recommended.

The *Corporate Standard* also allows reporting of GHG removals[19], but these must also be reported separately from the scopes (i.e., from the GHG inventory results). However, it does not provide guidance on methods for calculating removals, and until consensus methods are developed, the reporting of

[19] Removals represent the withdrawal of GHGs from the atmosphere as a result of biological sinks (e.g., forests) or technological sinks (e.g., carbon capture and storage).

removals remains optional.

Thus, biogenic CO_2 flows are treated as carbon neutral in the main inventory results, meaning that both CO_2 removals and emissions are excluded from scopes 1, 2, and 3. To maintain consistency with this treatment, the GHG Protocol (2024) recommends using the GWP for **non-fossil methane** when characterizing biogenic CH_4 emissions. This GWP value excludes the climate effect associated with methane's eventual oxidation to CO_2, aligning with the principle that biogenic CO_2 flows are not included in the results.

For example, CO_2 removal that occurs during biomass growth for biofuel production should not be included in the emission factor of biofuel production (in scope 3, category 3). Instead, an organization using this fuel could report the CO_2 removal separately, outside of its scope 3 inventory. Likewise, any CO_2 emissions resulting from the combustion of the biofuel must also be reported separately, outside of the scopes. In contrast, biogenic CH_4 emissions from combustion must still be included, using the non-fossil methane GWP value to ensure consistency with the GHG Protocol's treatment of biogenic carbon flows.

These requirements and recommendations are specific to the *Corporate Standard* and *Scope 3 Standard* and reflect historical and current organizational practices for reporting biogenic emissions. They are also aligned with the requirements of the *Agricultural Guidance*, which serves as a supplement to the *Corporate Standard* and provides additional guidance for agricultural organizations. Nevertheless, the way biogenic emissions are calculated and reported is likely to change significantly following the recent publication of the GHG Protocol *Land Sector and Removals Standard* in 2026.

7.1.2 Land Sector and Removals Standard

The *Land Sector and Removals Standard* was published at the beginning of 2026. It "establishes requirements and recommendations to account for, report, and track GHG emissions, CO_2 removals, and other relevant metrics that reflect anthropogenic activities in the land sector, as well as other CO_2 removal technologies" (GHG Protocol, 2026). It acts as a supplement to the *Corporate Standard* and *Scope 3 Standard* and will be complemented by the *Land Sector and Removals Guidance*, which is expected to be published in 2026.

The standard introduces several new concepts and requirements for organizations with land-based activities within their value chains. This section is not intended to provide an exhaustive analysis of these changes and new concepts, but rather a brief overview of how biogenic carbon is addressed in this new standard.

First, the *Land sector and Removals Standard* requires organizations to report emissions across distinct **accounting categories** and **subcategories**. These categories differ from value chain classification (i.e., scopes and categories). Instead, they refer to specific **types of emissions**, such as land use change emissions[20], land management biogenic CO_2 emissions, biogenic product emissions, etc. Thus, biogenic CO_2 emissions and removals are no longer treated as a single distinct category, as in other GHG Protocol standards where they are reported separately, but are instead divided into several accounting categories:

- **Land management net biogenic CO_2 emissions and removals** (two accounting categories): Net land carbon stock changes due to ongoing land management practices (e.g., grazing, tilling);

[20] Land use change emissions are treated in the section 8.

- **Land use change emissions** (which also include CH_4 and N_2O emissions): "Emissions (primarily from carbon stock losses) due to recent land conversion" (GHG Protocol, 2026);
- **Biogenic product emissions**: "Gross CH_4, N_2O, and, if applicable, CO_2 emissions from combustion, biodegradation, or other losses from biogenic product carbon pools to the atmosphere" (GHG Protocol, 2026).
- **Biogenic product carbon storage**: "Annual or annualized changes in carbon stored in biogenic product carbon pools during the use phase of biogenic products associated with the reporting company's value chain" (GHG Protocol, 2026).

The different accounting categories and subcategories are separated between a *Physical GHG inventory*, which acts as the main GHG inventory[21], and additional accounting categories, which are reported separately. Figure 7-1 shows the Physical GHG inventory, which includes the accounting categories and subcategories defined above[22,23].

Figure 4.1 **Required and optional accounting categories and subcategories for land sector value chains**

	Physical GHG inventory					
	Emissions					Removals
Accounting category	Fossil fuel and industrial emissions[a]	Land emissions				Removals
Accounting subcategory		Land use change emissions[b]	Land management net biogenic CO_2 emissions	Land management production emissions	Biogenic product emissions[c]	Land management CO_2 removals
Scope 1						
Scope 2						
Scope 3						
Reference	Corporate & Scope 3 Standards	Chapter 7	Chapter 9	Chapter 10	Chapter 11	Chapter 12 & 13

Required categories   Optional categories   Not applicable

Note. Adapted from *Land Sector and Removals Standard* (Figure 4.1, p.18), by GHG Protocol, 2026. Copyright 2026 by World Resources Institute and World Business Council for Sustainable Development. https://ghgprotocol.org/land-sector-and-removals-standard.

Figure 7-1: Accounting categories and subcategories of the *Land Sector and Removals Standard*

[21] The *Physical GHG inventory* reports emissions and removals figures without double counting by the same entity and is independent of GHG trades such as carbon credits.

[22] The *Land Sector and Removals Standard* also provides a reporting template for additional accounting categories, which is not shown in Figure 7-1.

[23] The *Land management production emissions* accounting category is not covered here as it does not include biogenic CO_2 emissions.

Second, the standard introduces two complementary approaches for measuring and reporting emissions: *stock-change accounting* and *flow accounting*. **Stock-change accounting** (net fluxes) focuses on the annual change in carbon stocks within defined pools (e.g., soil, biomass, or products), reporting the net balance between emissions and removals over the reporting period. In contrast, **flow accounting** (gross fluxes) tracks the actual emissions to and removals from the atmosphere separately, without netting them. For example, an increase in soil carbon would be reported as a net removal under stock-change accounting, whereas flow accounting would separately report gross CO_2 removals by biomass and any CO_2 released through decomposition.

The standard now explicitly requires the reporting of **land management net biogenic CO_2 emissions**. This means organizations must account for and report these emissions using a stock-change accounting approach. If the net change is negative (i.e., decrease of the carbon stock), organizations must report emissions within a "*Land management net biogenic CO_2 emissions*" accounting category, whereas if the net change is positive (i.e., increase of the carbon stock), organizations may optionally report CO_2 removals within a "*Land management CO_2 removals*" accounting category. Reporting CO_2 removals, however, requires organizations to meet specific requirements related to traceability, data quality, permanence and allocation.

From a biogenic carbon accounting perspective, this represents a paradigm shift compared to the treatment of land management emissions in other GHG Protocol corporate standards. Indeed, the *Land Sector and Removals Standard* now recognizes that changes in carbon stocks associated with land management are not simply carbon neutral. They must now be reported within the organization's main GHG inventory, called the Physical GHG inventory in the standard.

For **biogenic product emissions**, the *Land Sector and Removals Standard* states that "Biogenic product CO_2 emissions are not zero, and biogenic products cannot be assumed to be carbon neutral" (GHG Protocol, 2026). Biogenic emissions associated with products purchased, consumed, or sold by the reporting organization (excluding food and animal feed) must be calculated and reported. More specifically, this refers to emissions related to the carbon contained in these products. Reporting shall occur either within the Physical GHG inventory or under an additional accounting category, depending on whether some accounting categories are included for the bio-based product(s). When the organization accounts for land-related carbon stock changes associated with the product (i.e., land management net biogenic CO_2 emissions and removals) as well as land carbon leakage[24], biogenic product CO_2 emissions may be reported separately under an additional accounting category. This approach is consistent, as CO_2 sequestration during biomass growth is not reflected in land emissions under these conditions; including product emissions within the Physical GHG inventory would therefore lead to a mass balance inconsistency.

Conversely, when the two conditions above are not met – i.e., when the company does not account for land emissions and associated land carbon leakage for the bio-based product – biogenic CO_2 emissions must be reported within the Physical GHG inventory "*Biogenic production emissions*" accounting category. Because the CO_2 sequestration associated with the carbon in the product is not accounted for within land emissions in the Physical GHG inventory, reporting biogenic product CO_2 emissions in this way results in a mass balance inconsistency. While this requirement may be somewhat inconsistent from a scientific perspective, it can serve as an incentive for organizations to adopt a more comprehensive life cycle

[24] For more information on land carbon leakage, see Chapter 8 of the *Land Sector and Removals Standard*.

approach to bio-based products, including both land emissions and land carbon leakage.

Regarding **product carbon storage**, reporting both agricultural and technological carbon dioxide removal (TCDR) based product storage is optional. Product carbon storage may be reported separately in the "*Product carbon storage*" accounting category, using a stock-change accounting approach. Therefore, product carbon storage is not fungible with emissions or removals reported within the Physical GHG inventory and, for instance, would not be accounted for when tracking progress towards an SBTi emission reduction target.

7.2 Biogenic carbon in LCA

The issue of biogenic carbon is not treated in *ISO 14040/44* and *ISO 14072*. However, within the LCA field, three main approaches exist to deal with biogenic carbon: the *carbon neutrality approach* (also called the *0/0 approach*), the *-1/+1 approach*, and the *dynamic approach*.

The **carbon neutrality (0/0) approach** assumes that the flows of biogenic carbon to and from the atmosphere over the product life cycle are equal (i.e., the carbon sequestered in biomass used in the product is released during its use or end-of-life stages). Under this assumption, the net biogenic CO_2 emissions are considered to be null. As such, this method does not account for permanent or temporary carbon storage. This approach can be applied at the inventory stage, where biogenic CO_2 emissions are neither inventoried nor characterized, or at the impact assessment stage, where biogenic CO_2 emissions are inventoried but assigned a characterization factor of zero. Under this approach, other biogenic GHGs are given adjusted characterization factors (SCORE LCA, 2024). The carbon neutrality approach (0/0) is implemented in many LCIA methods. However, this approach has been widely criticized because removal and emissions flows are often not identical (e.g., if the stored carbon is released into the atmosphere in different forms (CH_4, CO) or if it is permanently stored (e.g., by landfilling)). Moreover, the 0/0 approach does not ensure mass balance in processes, as some flows are omitted.

The **-1/+1 approach** inventories and characterizes all biogenic GHGs over the product life cycle, multiplying flows entering the land or product carbon pools by -1 and those emitted in the atmosphere by +1. These flows are then characterized with the same GWP values as fossil carbon GHGs and summed over the product life cycle. This approach is also implemented in some LCIA methods. It addresses the main criticisms levelled at the 0/0 approach and is required in many LCA standards such as *ISO 14067*, *PAS 2050* (BSI, 2011) and *EN 15804+A2* (CEN, 2019). However, while permanent storage is accounted for under this approach (when removals outweigh emissions), temporary storage is not.

The **dynamic approach** tracks flows of emissions and removals of biogenic GHGs over time throughout the product life cycle, with the flows characterized with adapted GWP values. Different approaches have been adopted, such as the *ton.year* approaches (Moura Costa & Wilson, 2000; Fearnside et al., 2000) and the *GWPbio* approach (Cheurbini et al., 2011). Since the flows are tracked through time, this approach enables accounting for temporary carbon storage (as well as permanent storage) and is recommended for product systems involving longer biogenic carbon cycles (e.g., forest biomass systems). However, this approach has disadvantages at the operational level, as it requires a much more comprehensive inventory that includes the timing of emissions. Moreover, the dynamic approach is not operationalized in the software commonly used in LCA (e.g., SimaPro, openLCA), which requires the use of other tools. Given the additional effort and complexity involved in applying these tools, practitioners tend to prefer static approaches (0/0 and -1/+1 approaches).

7.3 Comparison of approaches – Biogenic carbon

The approach used in the *Corporate Standard* and *Scope 3 Standard* is equivalent to a 0/0 approach, which assumes carbon neutrality for biogenic CO_2 flows. Under these standards, biogenic CO_2 emissions are required to be reported, and removals may be reported optionally, but they are disclosed separately from the main results of the GHG inventory. As a result, they do not affect the reporting organization's emissions totals.

In contrast, the newer *Land Sector and Removals Standard* proposes a hybrid approach that incorporates elements of both the 0/0 and -1/+1 approaches. Emissions and removals associated with land management are accounted for within the core inventory, called in the standard the *Physical GHG Inventory*. The accounting approach used to quantify these flows (the stock-change accounting) tracks changes in carbon stocks over time. This approach is less commonly used in LCA, where studies typically focus on both one-directional CO_2 flows (i.e., emissions and removals).

However, the treatment of biogenic product CO_2 emissions and product carbon storage is closer to a carbon neutrality (0/0) approach. CO_2 removals associated with carbon stored in products (e.g., during the growth of biomass) are not included in "*Land emissions*". Consequently, biogenic product CO_2 emissions are reported outside the main GHG inventory, within an additional accounting category, when the reporting organization meets the criteria defined in the standard. These criteria are intended to ensure completeness of the accounting categories associated with the relevant bio-based product. If the company does not meet these criteria, the biogenic product CO_2 emissions must instead be reported within the Physical GHG Inventory, which may create an inconsistency in the biogenic carbon mass balance within that inventory.

Similarly, emissions related to TCDR-based products are also reported in an additional accounting category when the organization can demonstrate that the carbon contained in the product was technologically removed from the atmosphere. In this case, the associated technological CO_2 removal is not accounted for in the inventory. Consequently, the eventual emission of this technologically removed carbon is also excluded from the main GHG inventory. This treatment is therefore comparable to a 0/0 accounting approach, assuming carbon neutrality of biogenic CO_2 flows.

Overall, there are no fundamental differences between the **GHG Protocol**'s approaches and those commonly used in **LCA** to address **biogenic carbon flows**. The *Land Sector and Removals Standard* proposes a structured emissions reporting framework that disaggregates an organization's emissions into distinct accounting categories. These categories draw on accounting approaches that are widely used in LCA, namely the **-1/+1 approach** and the **0/0 (carbon neutrality) approach**.

However, a difference lies in how **product carbon storage** is treated. In LCA, when a system results in carbon storage, it is typically assessed using a **-1/+1 approach** to reflect the benefit associated with carbon storage. In contrast, under the *Land Sector and Removals Standard*, carbon storage associated with **biogenic products** is reported separately and is not included within emissions and removals reported in the Physical GHG Inventory. This treatment is nevertheless consistent with the standard principles of **conservativeness** and **permanence**, and the fact that the standard is used to track progress toward emission reduction targets.

8. LAND USE CHANGE

Land use change (LUC) refers to the conversion of land from its original state due to human interventions, such as agriculture, forestry, mining, construction, or industrial development (SCORE LCA, 2024). LUC emissions and removals occur as a result of land conversion from one land use category (i.e., purpose) to another.

LUC effects can be either **direct** or **indirect** (SCORE LCA, 2024). *Direct LUC* (dLUC) occurs directly on the land used by the system under study (e.g., growing biomass on land previously used for grazing or forestry). In contrast, *indirect LUC* (iLUC) refers to the chain of land use change effects triggered by market-mediated responses to direct LUC associated with the studied system. For instance, a land repurposed (e.g., for biofuel crops) could displace food crop demand to other areas, potentially leading to compensatory deforestation or land conversion in these other areas.

LUC impacts may be positive (e.g., CO_2 sequestration through photosynthesis during vegetation regrowth after agricultural land abandonment) or negative (e.g., loss of biomass and soil carbon due to land clearing or logging, decomposition of harvested products, emissions from peatland drainage and burning, land degradation).

8.1 Land use change in the GHG Protocol

Historically, because of a lack of clear guidance, organizations following the GHG Protocol have often left out LUC emissions from their inventories. This is because LUC emissions are not addressed in the *Corporate Standard*. However, the *Agricultural Guidance*, which supplements the *Corporate Standard*, explicitly includes guidance on LUC emissions as well as other land management-related emissions (i.e., land use emissions). Its main goal is to “promote sector-wide adoption of emissions management practices by harmonizing how agricultural companies worldwide measure and report their emissions” (GHG Protocol, 2014).

According to the *Agricultural Guidance*, when dLUC leads to a reduction in carbon stocks, the associated CO_2 emissions should be reported under scope 1. Conversely, carbon removals from dLUC should be reported separately, like other removals are. While the document references IPCC methods, it does not prescribe a specific methodology for estimating dLUC emissions and provides no guidance for accounting iLUC.

The new *Land Sector and Removals Standard* requires the inclusion of both direct and indirect emissions associated with LUC, which constitute a standalone **accounting category** within the GHG inventory. The standard requires selecting the most accurate calculation method based on data availability and the level of traceability an organization has to the land associated with its value chain. More specifically, it establishes the following hierarchy of approaches:

- **Land management unit-level direct LUC**: an approach that quantifies emissions associated with LUC on the specific parcels of land where the organization’s products are sourced. This implies direct causation, meaning that the impacts happen where the product is sourced.
- **Jurisdictional direct LUC (jdLUC)**: an approach that estimates LUC emissions at a subnational or national level (e.g., province, state, or country) and allocates them to products based on their

sourcing region. This approach relies on geographically explicit data and assumes a stronger, though not fully direct, link between production and land use change within the jurisdiction.

- **Statistical land use change (sLUC)**: an approach that allocates responsibility for LUC emissions within a given region to the commodities produced in that region, based on land occupation or expansion. This approach provides a proxy and does not imply direct causation (i.e., impacts may be attributed to a product even if it did not directly cause any land use change).

The standard requires the use of a 20-year assessment period for annual crops or land-based products with a cultivation cycle or rotation period of 20 years or less. For products with a cultivation cycle or rotation period exceeding 20 years, the length of that cycle or period must be used as the assessment period. It also requires LUC emissions to be distributed over the assessment period using a linear discounting approach, which assigns a larger share of the emissions to products grown closer in time to the year of land conversion.

Removals associated with land conversion (e.g., carbon sequestration from the establishment of perennial crops such as olive groves on previously degraded or abandoned land) are not comprehensively addressed in the standard. It states that "When LUC results in net removals or removals following an initial conversion that resulted in emissions, companies shall first account for the gross LUC emissions of the initial land use change, and then may separately account for the land management net CO_2 removals […]" (GHG Protocol, 2026). According to this requirement, only companies using primary data and conducting analyses at a fine geographic resolution would be able to report LUC removals, provided they also comply with the removals requirements. In most cases, removals associated with LUC would be excluded, as the use of secondary data (e.g., jdLUC or sLUC) does not allow the requirement cited above to be met.

8.2 Land use change in LCA

While they are not specifically addressed in *ISO 14040/44* and *ISO 14072*, LUC emissions are generally accounted for in the LCA field. Nearly all LCA standards (e.g., *ISO 14067*, *PAS 2050*, *PEF*) require the inclusion of dLUC emissions. Moreover, most LCI databases include dLUC emissions in their processes (e.g., in ecoinvent, Agri-footprint [Blonk et al., 2025], Agribalyse [Cornelus et al., 2024], and Sphera Managed LCA content [Sphera, 2026]).

The most commonly used method is the IPCC Tier 1 method (IPCC, 2006), recommended by the ILCD. It estimates GHG emissions from land use change based on the difference in carbon stock per hectare between two land uses, amortized linearly over at least 20 years. This method is widely applied in LCA because all required data are provided by default. Other commonly used approaches include those proposed in *PAS 2050*, the Blonk tool, and the method by Müller-Wenk & Brandão (2010).

However, iLUC emissions are rarely considered in LCA studies. This is largely due to the prevailing view that iLUC does not align with attributional LCA, which remains the main approach. However, new methods are being developed and may facilitate their integration in the future.

8.3 Comparison of approaches – Land use change

The **treatment of LUC emissions** differs between the GHG Protocol and LCA frameworks, both in scope and in maturity. LCA standards have traditionally required the inclusion of dLUC emissions, and most LCI databases systematically integrate these emissions into their datasets using established methods, such as the IPCC Tier 1 approach. In contrast, the GHG Protocol has historically lacked clear guidance on LUC, leading many organizations to omit these emissions entirely.

The recent publication of the *Land Sector and Removals Standard* is nevertheless expected to lead more organizations to quantify and report emissions associated with LUC. The recommendations and requirements of this standard are broadly consistent with common practices in the LCA community, particularly regarding the choice of assessment period and the use of a discounting approach.

A significant divergence between the two approaches concerns the **inclusion of LUC-related removals**. In LCA, such removals are commonly included, particularly when agricultural stages are modelled using LCI datasets. For example, the ecoinvent database incorporates removals associated with LUC, which can provide a significant advantage to certain products in specific geographies. In contrast, removals associated with LUC are not comprehensively addressed in the *Land Sector and Removals Standard*. Its requirement regarding the inclusion of removals associated with LUC implies that organizations using secondary data (e.g., jdLUC or sLUC) cannot include them. This highlights an important implication: practitioners seeking to align with this new standard should exercise caution when using LCI datasets that include LUC removals, and may need to exclude or adjust these data to ensure consistency with the standard.

Another difference, although minor, lies in **how the term dLUC is defined across the two approaches**. In LCA, dLUC generally refers to any LUC emissions directly linked to a sourced product, regardless of whether these emissions are calculated using primary data (i.e., directly tied to the specific field where the LUC occurred) or derived from statistical approaches that provide a proxy, such as those used in LCI databases. In contrast, the GHG Protocol places stronger emphasis on causation: LUC is considered “direct” only when the emissions are demonstrably caused by the product itself. As a result, sLUC is not considered a form of dLUC under GHG Protocol definitions.

9. MULTIFUNCTIONALITY

9.1 Multifunctionality in the GHG Protocol

A **multifunctional system** is one that **delivers several outputs**, whether products or services. A company, for instance, typically markets several products, offers various services, and performs other secondary functions (e.g., employing people). As such, it is a multifunctional system. When accounting for corporate GHG emissions, the aim is to establish the environmental profile of the whole organization, without isolating any particular function. Multifunctionality in the foreground system (i.e., within the organization itself) is therefore not addressed in organizational GHG accounting. In specific cases, however, it may be appropriate to address multifunctionality that can arise when organizations use primary data from suppliers or generate or use recyclable materials.

9.1.1 Use of primary data from suppliers

Multifunctionality can arise when an **organization collects primary data** (either inputs and outputs or emissions data) **from suppliers**, that originate from a single facility or other system producing multiple outputs. These outputs are called *co-products*, which refer to multiple products produced by the same system. For example, a reporting organization may need to calculate the emissions associated with a purchased product using the supplier's GHG inventory results. If the supplier manufactures multiple products, the emissions in its GHG inventory are related to all of them. Therefore, multifunctionality must be addressed to isolate the emissions associated with the specific product purchased by the reporting organization.

The collected primary data may be collected at varying levels of detail and granularity, as shown in Table 9-1. Further information about primary and secondary data is provided in *Technical Report 2*.

Table 9-1: Levels of primary data

Data type	Description
Product-level data	Cradle-to-gate GHG emissions from the product of interest.
Activity-, process- or production line-level data	GHG emissions and/or activity data for the activities, processes, or production lines that produce the product of interest.
Facility-level data	GHG emissions and/or activity data for the facilities or operations that produce the product of interest.
Business unit-level data	GHG emissions and/or activity data for the business units that produce the product of interest.
Corporate-level data	GHG emissions and/or activity data for the entire corporation.

Note: Reproduced from the *Scope 3 Standard* (Table 7.7, p.80), by GHG Protocol, 2011a.
https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf

Product-level data are the only data type that is already allocated by suppliers. For all other data types of data in Table 9-1, emissions or flows (i.e., inputs and outputs) from the system would need to be allocated if the organization generates multiple outputs. The GHG Protocol defines allocation as "[…] the process of partitioning GHG emissions from a single facility or other system (e.g., activity, vehicle, production line, business unit) among its various outputs" (GHG Protocol, 2013a).

This is common for purchased goods (scope 3, category 1), where reporting organizations are more likely to collect primary data than to rely on secondary data (e.g., generic emission factors). For example, an organization may purchase a product from a supplier that manufactures a wide variety of products in a single plant. If this supplier provides facility-level emissions data to the reporting organization, these emissions values need to be allocated to the supplier's different products. This enables the reporting organization to estimate specific GHG emissions of the product it purchases from the supplier. The need to allocate suppliers' emissions may also arise for multiple other scope 3 categories, but it is less common.

However, allocation has significant limitations and should be used only when no better quality data is available. Indeed, in the previous example, the allocation may not accurately reflect that the product purchased by the reporting organization could have a higher emissions intensity than other products manufactured by the supplier. For this reason, the GHG Protocol first recommends avoiding allocation, if possible, by collecting more detailed data through one of the following approaches:

- Obtaining product-level emissions data from suppliers following the GHG Protocol *Product Standard*;
- Separately sub-metering energy use and other activity data, which provides product-level activity data directly, thus eliminating the need for allocation;
- Using engineering models to separately estimate emissions related to each product produced.

These approaches essentially involve subdividing a multifunctional system into mono-functional systems (i.e., product-level data). If allocation cannot be avoided through subdivision, the GHG Protocol then recommends performing allocation.

As a general rule, the standard advocates for allocating the emissions of an activity based on an underlying physical relationship, which it refers to as *physical allocation*. However, the GHG Protocol's definition of physical allocation is based on using physical properties (e.g., mass, volume, energy) of outputs. Thus, the GHG Protocol does not state an allocation based on **actual underlying physical relationships** (which relies on causality principles) as an option. Underlying physical relationships are further explained in section 9.2.1.c))

If using physical properties is not feasible or adequate, the GHG Protocol recommends an economic allocation as a last option. However, this hierarchy is not a requirement of the GHG Protocol. In the *Scope 3 Standard*, it is acknowledged that the most appropriate allocation method for a given activity depends on individual circumstances. Various criteria for choosing a method are indicated in the GHG Protocol, including selecting the approach that best reflects the causal relationship between the production of the outputs and the resulting emissions.

The data type (see Table 9-1) affects the quality of the allocated emissions data. While prioritizing product-specific data to avoid allocation is recommended, collecting primary data at the most specific level of aggregation possible is equally important. For example, an allocation based on facility-level data will be more accurate than one based on corporate-level data. A finer level of aggregation generally reduces the number of co-products generated by the system, thus reducing uncertainty in the allocated emissions. In addition, the use of highly aggregated data, such as at the corporate level, leads to boundary issues. For example, if an organization collects data from a supplier that has conducted a GHG inventory including downstream emission sources (e.g., downstream transportation, use of sold products), the allocated emissions values will include emission sources that should not be considered in a cradle-to-gate emissions factor. The specific boundaries to consider before making an allocation are unclear and not prescribed in the GHG Protocol's standards and guidance documents.

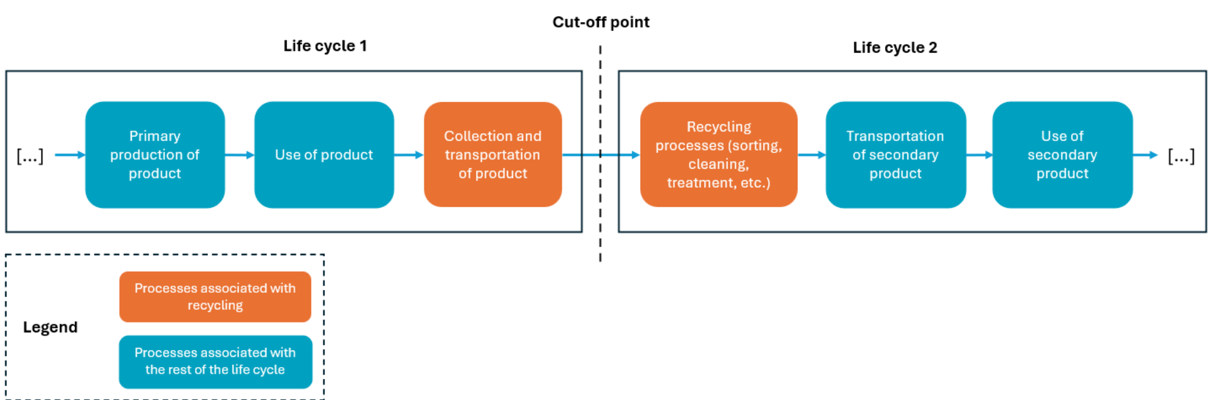
Finally, allocation is typically unnecessary when the organization relies on secondary data, as multifunctionality is already managed in the background data (e.g., in LCI datasets or emission factors used). For example, an organization purchasing electricity from a cogeneration unit does not need to perform allocation if it relies on secondary data but must do so if it collects primary data from its supplier, unless this supplier provides allocated data (e.g., results of a product LCA).

9.1.2 Recycling activities

Recycling processes are **multifunctional**: they **treat waste** and **generate a secondary product** (i.e., by-products). Thus, in an organizational GHG inventory, the impacts of recycling processes must be split between the upstream entity that generates the waste, and the downstream entity that uses the secondary product.

For recyclable materials, the **GHG Protocol** recommends using the ***recycled content*** (or ***cut-off***) approach for recyclable materials, but does not require it. This approach involves tracing a "line" (*cut-off point*) in the life cycle of a recyclable material, between the primary and secondary systems. The system that generates the waste bears the burden upstream of that cut-off point, while the system that uses the secondary material bears the burden downstream of that cut-off point.

This approach can be applied with different cut-off points. The GHG Protocol suggests placing the cut-off point after waste collection, meaning that organizations generating outgoing by-products must account for the transportation emissions associated with delivering recyclable materials to the processing site. The recycled content approach and this specific cut-off point are illustrated in Figure 9-1.



"Life cycle 1" corresponds to the life cycle of the primary product, whereas "Life cycle 2" corresponds to the life cycle of the secondary product. The cut-off point, according to the recommendation of the GHG Protocol, is set after the collection and transportation of the primary product at its end-of-life. Thus, the organization generating the recyclable material accounts for emissions associated with its collection and transportation up to the processing site in scope 3, category 5 (waste generated in operations). The organization purchasing the secondary product accounts for emissions associated with its recycling (sorting, cleaning, treatment, etc.) in scope 3, category 1 (purchased goods and services), unless it controls these processes. The transportation of the secondary product between recycling facilities and the organization is accounted for in scope 3, category 4 (upstream transportation and distribution).

Figure 9-1: Illustration of the recycled content (cut-off) approach

However, the GHG Protocol allows flexibility in defining the cut-off point, emphasizing the need for consistency between its placement for both purchases of secondary products (whose emissions are accounted for in scope 3, category 1) and generated recyclable materials (whose emissions are accounted for in scope 3, category 5).

The GHG Protocol also permits organizations to apply alternative approaches if they better suit specific materials within their supply chains. For instance, the *closed-loop approximation method*[25] can be relevant when a recycled material output retains the same inherent properties as its virgin material input.

However, the GHG Protocol explicitly prohibits using system expansion (i.e., substitution) to calculate and report avoided emissions from generated recyclable materials.

9.2 Multifunctionality in LCA

In product LCA, multifunctionality is often addressed by isolating one of a system's functions and assessing its potential environmental impacts. The presence of co-products within a product system and recycling activities generally involves dealing with multifunctionality. In **O-LCA**, allocation may be required when organizations collect data from multifunctional systems (e.g., from suppliers), as it is with the GHG Protocol. In such cases, *ISO 14072* recommends applying the allocation procedures outlined in *ISO 14040/44*, which are detailed in the following subsections.

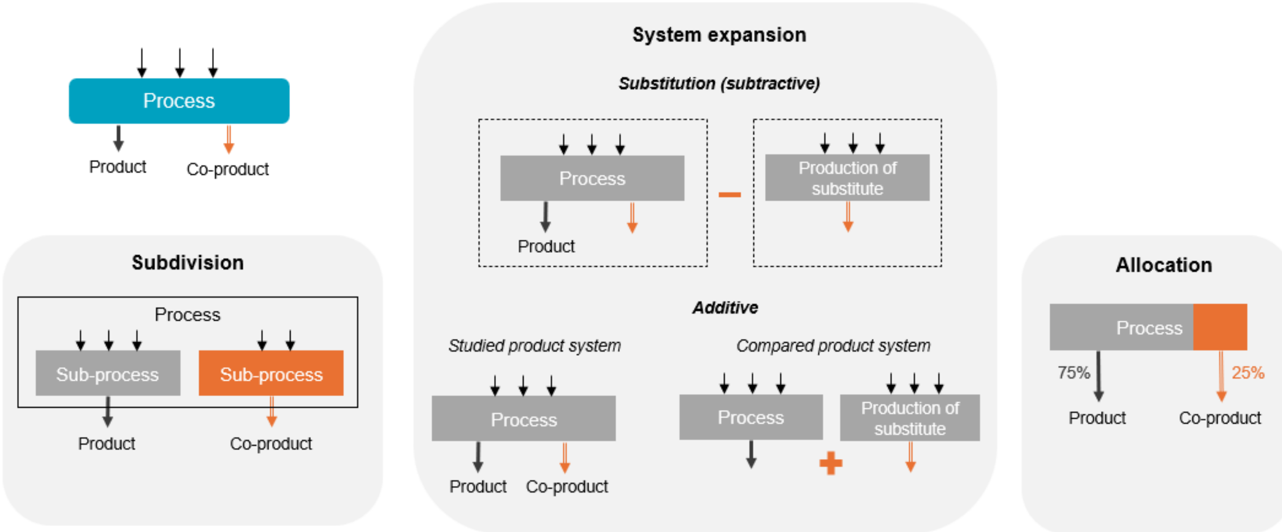
9.2.1 Co-products

ISO 14044 defines co-products as “any of two or more products coming from the same unit process or product system” (ISO, 2006). Generally, in LCA, co-products are categorized as such when they have a positive economic value[26]. Examples of co-products include heat and electricity from cogeneration.

ISO 14044 outlines a hierarchy of approaches to manage multifunctionality, offering guidance on how to avoid allocating impacts or allocate them among co-products. These approaches are illustrated in Figure 9-2.

[25] This approach is described in section 9.2.2.

[26] The ecoinvent database refers to co-products as *allocatable products*.



Note: Reproduced from *Analyse du cycle de vie de la biomasse énergie : état de l'art, enjeux méthodologiques et recommandations* (Figure 5-14, p.80), by Patouillard et al., 2022. https://scorelca.org/etudes/?etude_search=ciraig

Figure 9-2: Illustration of the different approaches to deal with multifunctionality in LCA

a) Subdivision

The *subdivision*, which should be prioritized when possible, consists of separating a multifunctional process into monofunctional processes. It applies to processes that are not truly multifunctional, and where the flows required to produce each product can be distinguished. For example, milk production involves multifunctional processes, since livestock activities also enable the production of meat and leather. Nevertheless, in this case, milking steps can be entirely allocated to milk and do not require any allocation. This corresponds to subdivision. However, other stages, such as feed production, cannot follow this logic and require a different approach.

b) System expansion

The second approach is *system expansion*, in which system boundaries are extended to include additional functions associated with co-products. This approach can be either *subtractive* or *additive*.

Subtractive system expansion, also called *substitution*, consists of subtracting the impacts of products substituted by co-products to create a monofunctional process. In the previous example of milk production, this approach would involve subtracting from the product system the impacts of producing an equivalent quantity of meat and leather on a dedicated farm.

Additive system expansion is done by redefining the system's functional unit to include the additional functions, which is relevant only for comparative studies. For example, if a comparative study were to examine the impacts of cow milk and plant-based milk, this approach would involve adding meat and leather production to the functional unit of the study, so that the plant-based milk would also have to deliver this additional function. However, this approach is rarely used in practice and is only applicable for comparative studies, therefore not relevant for obtaining an emission factor for a specific product. It is also not suitable for conducting organizational-level studies, which are non-comparative.

c) Allocation

Allocation should be used last and involves distributing the impacts generated by a process (and its upstream activities) among its various co-products or co-functions according to a defined allocation rule.

- *ISO 14040/44* recommends that, wherever possible, allocation should reflect *underlying physical relationships*, also known as *physical allocation*, which is based on a principle of physical causality between co-products. This type of allocation must reflect the actual physical cause-and-effect relationships within the system. In milk production, allocation between milk and meat is generally based on how the cow partitions feed energy among different physiological functions, reflecting physical cause-and-effect relationships. Specifically, the method uses a biophysical allocation formula that allocates environmental burdens based on the proportion of feed energy used for milk production (lactation) versus for growth and maintenance (leading to meat production).
- If such an allocation is not feasible, *ISO 14040/44* recommends using **other allocation keys**, such as economic, mass or energy relationships between co-products, without ranking them in a hierarchy.

ISO 14044 states that "allocation procedures shall be uniformly applied to similar inputs and outputs of the system under consideration" (ISO, 2006). This means that the allocation procedure used for a co-product that is an output of the system must be the same as that used for a similar co-product that is an input of the system.

9.2.2 Recycling activities

As mentioned above, recycling processes involve multifunctionality because they provide at least two co-functions: treating waste and generating secondary products. In LCA, the procedure of allocating burdens between primary and secondary systems is called *end-of-life allocation*.

In LCA, flows associated with recycling are often referred to as *by-products*[27]. They are characterized by having little or no economic value, but they are of interest for reuse or recycling in other processes.

By-products can be involved in a product system in two different ways:

- *Outgoing by-product*: A system generates a by-product. For example, the generation of digestate during biogas production.
- *Incoming by-product*: A system uses and processes a residue from another system. The process that valorizes the by-product can sometimes be referred to as a "recycling process". For example, recycling manure from dairy production as a fertilizer.

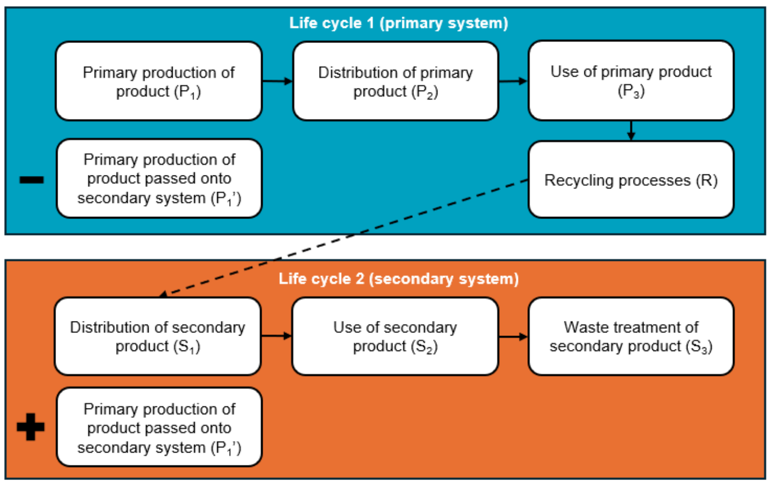
ISO 14044 states that its allocation principles and procedures (as defined by its hierarchy) also apply to by-products coming from reuse and recycling. However, the multifunctionality created by incoming or outgoing by-products is often managed using specific approaches. The main reason for this is that reuse and recycling may imply that flows linked to the extraction and processing of raw materials (primary production) and final disposal are shared by more than one product system (ISO, 2006). The main end-of-life allocation approaches are described below in an order that does not reflect a hierarchy.

[27] The ecoinvent database refers to by-products as *recyclable materials*.

a) Closed-loop approximation

A closed-loop allocation procedure applies to closed-loop product systems or open-loop product systems where no changes occur in the inherent properties of the recycled material (ISO, 2006). It is also known as the *0:100 approach*, the *end-of-life recycling approach* or the *avoided burden approach*.

The *closed-loop approximation* approach, illustrated in Figure 9-3, assumes that the recyclable material (**outgoing by-product**) replaces an identical quantity of virgin material in the secondary system. Therefore, the primary system accounts for the burden of recycling processes (R) and receives a credit (P_1') for the quantity of recyclable material passed on to the secondary product system, which is assumed to displace primary production. The secondary system considers the burden of the virgin material (P_1'), which is credited to the primary system.



Life cycle 1 = $P_1 + P_2 + P_3 + R - P_1'$
Life cycle 2 = $P_1' + S_1 + S_2 + S_3$
P_1' = Burdens of primary production for the quantity of primary product passed on to the secondary system

Figure 9-3: Illustration of the closed-loop approximation approach

Conversely, an *open-loop allocation* procedure applies to open-loop product systems in which the material is recycled into other product systems and undergoes a change in its inherent properties (ISO, 2006). Open-loop allocation approaches are described in the following points.

b) Recycled content or cut-off approach

As previously described, the *recycled content* (or *cut-off*) approach consists of tracing a “line” (cut-off point) in the life cycle of recyclable materials, between the primary and secondary systems. The system that generates the waste (i.e., outgoing by-product from the primary system) bears the burden upstream of that cut-off point, and the system that uses the secondary material (i.e., secondary system) bears the burden downstream of that cut-off point.

For example, the ecoinvent database uses waste collection as the cut-off point (prior to it). Therefore, **outgoing by-products** do not bear any burden for the system that generates them, and **incoming by-products** are available burden-free to recycling processes. The impacts of waste collection, pre-treatment and recycling processes are attributed to the secondary material, as shown in Figure 9-4.

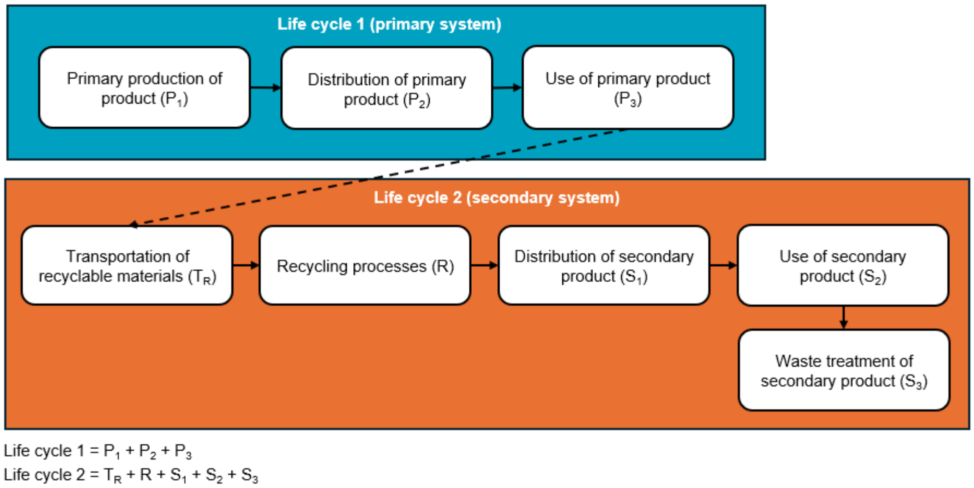


Figure 9-4: Illustration of the cut-off approach

However, this approach can be applied with a different cut-off point. For example, the *EN 15804* standard on core rules for construction products requires that waste processing of recyclable materials be accounted for up to the "end-of-waste" state. An outgoing by-product has reached the end-of-waste state when it meets certain criteria, including having a positive economic value (i.e., product can be sold). This means that the system that generates a recyclable material bears the burden of all processes required for it to reach the "end-of-waste" state.

c) 50/50 approach

The *50/50 approach* distributes environmental burdens and credits between the primary and secondary systems. In its generic form, this approach attributes 50% of the burdens associated with recycling processes to the primary system and 50% to the secondary system. One typical application of the 50/50 method also consists of attributing 50% of the burden of virgin material production and distribution (i.e., cradle-to-gate) and 50% of recycling processes to either system. Figure 9-5 shows a simplified illustration of this approach.

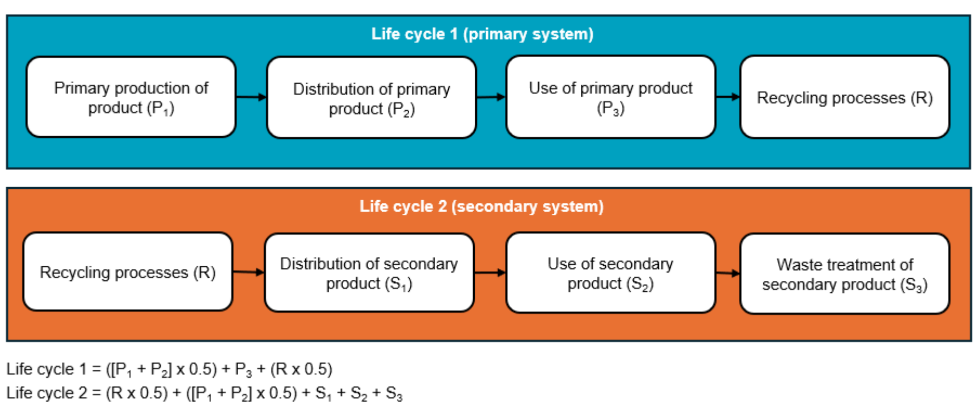


Figure 9-5: Illustration of the 50/50 approach

Another variation of the 50/50 approach is to credit the primary system for avoided primary production. When applied, the primary system typically receives a 50% credit for the outgoing by-product (e.g., scrap), while the secondary system assumes 50% of the burdens from producing the incoming by-product. The 50/50 approaches are often seen as a compromise between the cut-off and substitution approaches, aiming to reflect shared responsibility for recycling.

d) Circular Footprint Formula

The *Circular Footprint Formula* (CFF), developed under the PEF initiative, is an end-of-life allocation method that accounts for both the use of recycled materials (incoming by-products) and the recovery of materials at end-of-life (outgoing by-products). It allocates burdens and credits across the primary and secondary systems by introducing parameters related to material quality, market demand, and allocation factors for recycling and energy recovery. In comparison to other approaches that generally favour either incoming or outgoing by-products, the CFF aims to consider both by accounting for recycled content at the input side and recovery at the end-of-life. This approach can provide a more comprehensive view of circularity, though its application requires detailed data and calculations for each material, and is relatively complex to implement.

e) System expansion by substitution

The *system expansion by substitution* approach applies substitution to credit processes with the avoided burdens from supply chains that are displaced by the by-products they generate. This method takes a consequential approach and does not aim to divide burdens between primary and secondary systems. It is illustrated in a simplified example in Figure 9-6, both for outgoing and incoming by-products.

For an **outgoing by-product**, the valorization (i.e., recycling processes) is included within the product system boundaries until the substitutable product is obtained, and the impacts of the pathway replaced by this substitutable product are subtracted from the studied system. For example, biogas production generates digestate, which has the potential to replace mineral fertilizer production. In this case, system expansion involves subtracting the impacts of mineral fertilizer production from the biogas production system, based on the amount of agronomic nutrients substituted.

For an **incoming by-product**, the pathway that is substituted by processing this incoming by-product is included within the product system, and the burdens of this pathway are subtracted from those of the studied system. For example, in biogas production from manure, the usual valorization of manure as fertilizer is subtracted from the biogas production system using manure.

This approach shares similarities with the closed-loop approximation method, as it allocates a credit to the system that generates the recyclable material. However, it differs in several respects: it can be applied to open-loop systems and to cases where recycled materials degrade in quality during the recycling process, unlike the closed-loop approximation method. This is because it credits a substitute product rather than the primary production of the same product.

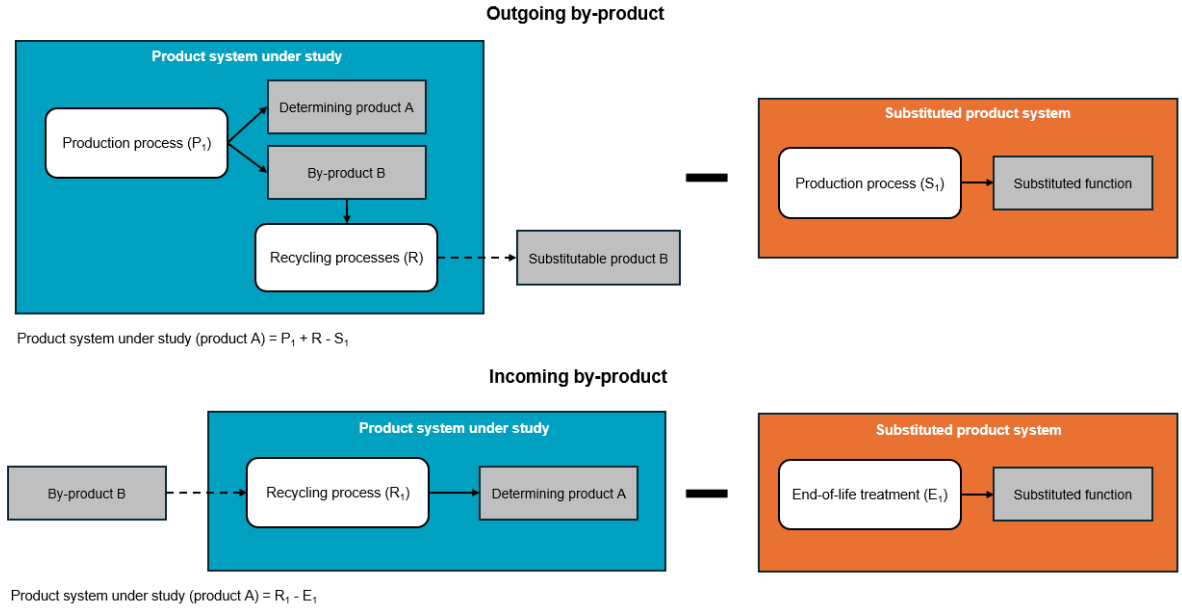


Figure 9-6: Illustration of the system expansion by substitution approach

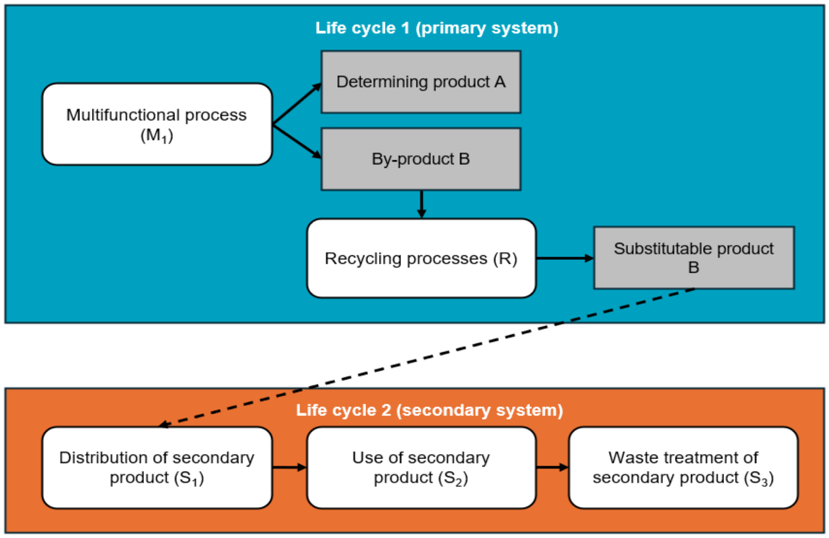
f) Allocation at the point of substitution

Under the *allocation at the point of substitution* (APOS) approach, the recycling processes associated with an outgoing by-product are attributed to the system that generates the flow, up until the substitutable product is obtained. An economic allocation of impacts is then performed at this point, after expanding the system. The allocation of impacts is thus calculated based on the amount of substitutable product generated rather than the outgoing by-product itself, and includes the processes required to make a substitutable product from a recyclable material (outgoing by-product). The APOS approach is illustrated with a simplified example in Figure 9-7.

For example, digestate from biogas production (M_1) must be processed (e.g., liquid-solid separation, drying) before it can be valorized as organic fertilizer (substitutable product B), which directly substitutes mineral fertilizers. Under the APOS approach, the biogas production system (primary system) would include the digestate processing steps (R), and an economic allocation would be performed at the point of substitution, based on the quantity and price of organic fertilizer produced. Therefore, the biogas production system (primary system) also carries some burden from the digestate processing steps (R), and the organic fertilizer carries some burden from biogas production and digestate processing steps (M_1 and R).

It should be noted that the APOS approach is mostly used in background systems[28] (ecoinvent offers an APOS system model), as its application in foreground systems is often impossible due to the scope of a given study.

[28] The background system consists of processes that are typically modelled using secondary data. In contrast, the foreground system consists of processes that are under the control of the decision-maker for which the LCA is carried out (Life Cycle Initiative, n. d.) and is therefore generally modelled using primary data.



Life cycle 1 = $(M_1 + R) \times AF_A$
Life cycle 2 = $(M_1 + R) \times AF_B + S_1 + S_2 + S_3$
AF_A = Economic allocation factor for determining product A, based on quantity produced and price
AF_B = Economic allocation factor for substitutable product B, based on quantity produced and price

This figure shows a simplified example where the primary system ("life cycle 1") corresponds to the cradle-to-gate of a process that generates a determining product and a by-product. Under the APOS approach, the recycling processes (transportation, sorting, cleaning, etc.) associated with by-product B are attributed to the primary system, up until the substitutable product is obtained. At this point (i.e., "point of substitution"), an economic allocation is performed based on the revenues generated by "Determining product A" and "Substitutable product B". The secondary system receives a portion of the primary system's burdens, based on the allocation factor for "Substitutable product B".

Figure 9-7: Illustration of the allocation at the point of substitution (APOS) approach

9.3 Comparison of approaches – Multifunctionality

9.3.1 Magnitude of the issue

The extent to which multifunctionality is a central issue varies between the GHG Protocol and LCA, primarily because in organizational GHG accounting, it is only relevant in the background system. It needs to be addressed only when an organization collects primary data from a supplier, and that data (e.g., inputs and outputs or emissions data) pertains to multiple products.

Furthermore, the approach chosen for managing waste-related multifunctionality typically has less influence on results compared to certain types of LCA studies, making it a less important methodological issue.

9.3.2 Co-product allocation procedures

The procedures proposed to address multifunctionality and the hierarchy in which they are organized differ between the two studied approaches. The main differences concern system expansion, the interpretation of "underlying physical relationships" and the hierarchy for allocation methods.

- **System expansion**: The *ISO 14040/44* standards recommend system expansion as the preferred approach when subdivision is not feasible. In contrast, the GHG Protocol does not allow system expansion to address multifunctionality, consistent with the GHG Protocol's approach of not accounting for avoided emissions in organizational GHG inventories. The O-LCA standard *ISO 14072* is consistent with this and does not allow system expansion.

- **Interpretation of "underlying physical relationships"**: *ISO 14040/44* and *ISO 14072* recommend that, wherever possible, allocation should reflect underlying physical relationships. In defining this type of allocation, LCA standards emphasize the principle of physical causality between co-products, requiring that allocation reflect the actual cause-and-effect relationships within the system. Conversely, the GHG Protocol interprets "underlying physical relationships" as using the physical properties of outputs, such as mass, volume, or energy. In practice, an allocation based on actual underlying physical relationships (using cause-and-effect relationships) would be quite rare in an organizational GHG inventory. Nevertheless, this difference in interpretation highlights how the two approaches handle multifunctionality.
- **Hierarchy for allocation**: The *ISO 14040/44* and *ISO 14072* standards stipulate that when allocation based on underlying physical relationships is not feasible, other relationships between co-products (e.g., economic or mass-based allocation) should be used. However, the framework does not prioritize any specific method, leaving the choice to the study's context. In contrast, the GHG Protocol establishes a clear preference: it recommends using physical allocation (based on mass, energy, volume, etc.) as the first choice, followed by economic allocation only if physical allocation is not relevant. This means that, under the GHG Protocol, mass, volume, or energy-based allocation should take precedence over economic allocation. However, the selection of an allocation method is not prescriptive in the GHG Protocol. The *Scope 3 Standard* states that organizations should select the approach that best reflects the causal relationship between the production of the outputs and the resulting emissions.

9.3.3 End-of-life allocation procedures

The GHG Protocol deals with end-of-life allocation specifically for recycling. It considers composting and incineration with energy recovery (waste-to-energy) as waste treatment; the impacts of these processes are therefore entirely attributed to the entity that generates them.

For recycling activities, the GHG Protocol provides relatively prescriptive guidance, giving organizations limited flexibility. By default, it recommends using the cut-off approach, placing the cut-off point after the collection and transportation of outgoing by-products. It also mentions that other approaches can be used if they are more suitable and relevant to specific products in the organization's value chain, notably the closed-loop approximation approach. For incineration with energy recovery (waste-to-energy), the GHG Protocol similarly recommends the cut-off approach, where emissions from incineration are allocated to the energy produced, and the organization generating the waste only accounts for waste collection and transportation.

As with allocation at the co-product level, the GHG Protocol does not allow the use of system expansion. Conversely, LCA offers a multitude of methods to suit the objectives of different types of study.

10. AVOIDED EMISSIONS

Avoided emissions represent the “positive” impact on society when comparing the GHG emissions of a particular solution (e.g., product, organization) to those of an alternative baseline scenario. An **avoided emission** is thus the **difference between GHG emissions that occur or will occur** (the “solution”) **and** GHG emissions that **would have occurred without the solution** (that of the baseline scenario) (Valeri et al. 2023).

10.1 Avoided emissions in the GHG Protocol

Organizational GHG accounting methods track GHG emissions and removals within defined inventory boundaries (i.e., organizational and operational boundaries). They do not consider system-wide impacts (i.e., those beyond scopes 1, 2, and 3), such as avoided emissions.

In the context of a GHG inventory, avoided emissions are those that would have otherwise happened, but that, as a result of an organization’s activities, did not happen (GHG Protocol, 2022). In addition to emissions arising from the use of their products (scope 3, category 11), some organizations may also quantify the avoided emissions resulting from their products' use compared to alternative products. For example, a high-performance tire manufacturer might be interested in calculating the avoided emissions from its low-friction tires, which reduce fuel consumption compared to conventional alternatives on the market.

The concept of “Scope 4” emissions was introduced by the WRI in 2013 to refer to avoided emissions. While the concept is not officially recognized by the GHG Protocol, it is gaining traction alongside the traditional GHG categories.

To understand and assess these impacts, organizations need to use intervention accounting methods[29], that estimate the system-wide impacts of actions relative to counterfactual baseline scenarios. They assess the GHG impacts of an action relative to the conditions most likely to occur in its absence. The GHG Protocol’s *Project Protocol* (GHG Protocol, 2005) provides methods for quantifying and reporting avoided emissions.

The GHG Protocol requires that any estimates of avoided emissions must be reported separately from an organization’s scope 1, 2 and 3 inventory, rather than included or deducted from the inventory. Thus, avoided emissions are not captured in corporate GHG inventory results. Other types of emission reductions occurring outside the value chain (e.g., those associated with the purchase of carbon offsets) cannot be aggregated with the results, but may be disclosed as supplementary information.

10.2 Avoided emissions in LCA

In a **comparative product LCA** study, the comparison between systems is made on the basis of the same function(s), quantified using the same functional unit. Thus, the results of a comparative LCA capture the difference in potential environmental impacts between two systems that deliver the same functions. This difference can, in the case of a more advantageous product, highlight the emissions avoided by this product compared with an alternative product.

In a **non-comparative product LCA**, avoided emissions are either included or excluded, depending on the study's goal and scope. They are sometimes calculated and declared separately in EPDs. For example, the

[29] For more information on intervention accounting methods, see section 2 of Valeri et al. (2023).

ISO 21930 standard[30] (ISO, 2017) includes a ''Module D'' for ''Benefits and loads beyond the system boundary''. This module provides optional supplementary information about the potential net benefits (i.e., avoided emissions) from reuse, recycling and energy recovery beyond the system boundary of the studied product system. However, in many cases, LCAs aimed at establishing the environmental profile of a product system do not consider avoided emissions.

In **product LCA**, avoided emissions can also be aggregated into results when multifunctionality is dealt with the system expansion approach (see section 9.2.1). This approach credits the product system with the avoided emissions resulting from one of its co-products. However, it should be noted that these avoided emissions are linked to the product system but are not necessarily directly linked to the product for which a study is conducted.

For example, in the case of electricity produced through cogeneration, the system expansion approach attributes a credit to the product system for displacing conventional heat generation. This credit reflects avoided emissions, but it pertains to the overall cogeneration process, not just to the electricity. In contrast, an example of avoided emissions specifically related to electricity would be those that occur when electricity displaces a more carbon-intensive energy source (e.g., fossil fuels) and is supplied to a remote area that previously lacked access.

Accounting for avoided emissions through system expansion helps isolate one of the system's multiple functions (in this case, cogeneration) to evaluate the environmental impacts specifically associated with one of the system's functions (in this case, electricity generation). They are therefore conceptually different from avoided emissions in the GHG Protocol, which generally refer to hypothetical emission reductions that result from the use of products sold by organizations.

In **O-LCA**, the system expansion approach is not permitted, consistent with the GHG Protocol's approach. Moreover, *ISO 14072* does not provide recommendations for reporting avoided emissions.

10.3 Comparison of approaches – Avoided emissions

The key distinction in avoided emissions is between organization-level studies (whether following the GHG Protocol or *ISO 14072*) and product-level studies, as avoided emissions are conceptualized and reported differently in each context.

At the **organizational level**, the term is commonly used and generally refers to emissions avoided through the use phase of a sold product or service, relative to a hypothetical baseline scenario. The methods typically used to calculate them are intervention-based approaches such as those outlined in the *Project Protocol*. Conversely, the term avoided emissions is less commonly used to refer to potential credits associated with an incoming by-product (e.g., the use of waste as an input) or an outgoing by-product (e.g., the supply of recyclable materials). This is because organizational studies are inherently multifunctional and do not aim to isolate a specific system function, and allocating credits for incoming or outgoing by-products through system expansion is not allowed in either the GHG Protocol or O-LCA approaches. Moreover, avoided emissions associated with the use of sold products are often much more significant.

At the **product level** (LCA), the concept of avoided emissions is less formalized. One reason for this is that in comparative LCAs, avoided emissions are inherently reflected in the comparison between systems under

[30] Sustainability in buildings and civil engineering works - Core rules for environmental product declarations of construction products and services.

study. It is also worth noting that the boundaries for avoided emissions in LCA are typically broader, as they encompass all life cycle stages. In contrast, under the GHG Protocol, avoided emissions are often limited to the use phase, as the guidelines do not explicitly require the adoption a life cycle perspective (e.g., the *Project Protocol*).

Moreover, in LCA, applying credits associated with co-functions of the studied systems is common, particularly when using system expansion (subtractive approach) to address multifunctionality. As mentioned earlier, some LCA standards also allow the separate reporting of avoided impacts (e.g., Module D in *EN 15804*). Thus, in LCA, avoided impacts may be either aggregated with or reported separately from the main results. By contrast, in organizational studies (GHG Protocol and O-LCA), avoided emissions are never aggregated with the reported results but may be disclosed separately as supplementary information.

11. REPORTING AND RESULTS INTERPRETATION

11.1 Reporting and results interpretation in the GHG Protocol

Under the GHG Protocol, organizations must report their scope 1 and scope 2 emissions in metric tonnes for each of the seven GHGs, as well as in metric tonnes of CO_2e (as a total). These emissions must be reported separately by scope, at a minimum. Scope 3 emissions, meanwhile, may be reported in CO_2e only, and must be broken down by scope 3 category.

As previously mentioned, biogenic CO_2 emissions must be reported separately from the scopes (i.e., separately from the inventory results). Avoided emissions and GHG trades (e.g., carbon offsets) must not be aggregated with inventory results but can be disclosed separately.

For organizations that have established a base year, they must report the base year itself, the rationale for choosing it, the base year emissions (by scope and category), and any adjustments made to the base year emissions, if applicable.

From a qualitative perspective, organizations are required to disclose a variety of information in their GHG inventory report. Key mandatory elements include:

- A list of included and excluded scope 3 categories or activities, with justifications for exclusions;
- A description of data sources (including both activity data and emission factors);
- The GWP values used;
- The calculation methods and allocation procedures applied;
- The percentage of emissions calculated using supplier-specific data, for each scope 3 category.

All required elements are detailed in section 9 of the *Corporate Standard* and section 11 of the *Scope 3 Standard*. Additional elements such as performance indicators and intensity metrics (e.g., CO_2e per tonne of product) are optional but recommended.

Regarding data quality assessment, the *Scope 3 Standard* requires that the quality of the reported data be described for each included category. While the GHG Protocol does not mandate a full data quality analysis, it strongly encourages organizations to select data sources based on data quality indicators (see section 7.3 of the *Scope 3 Standard*). It also recommends developing and implementing a data management plan, which includes conducting specific data quality checks.

For sources, processes, and/or activities that are significant to the inventory and/or have high uncertainty, the GHG Protocol suggests more in-depth reviews. One example of such a check is an uncertainty analysis, which, although optional, is discussed further in Appendix B of the *Scope 3 Standard*.

11.2 Reporting and results interpretation in LCA

ISO 14040/44 and *ISO 14072* standards require a wide range of elements to be disclosed in LCA reports, including:

- System boundaries;
- Data details;
- Allocation choices;
- Selection of impact categories.

These standards also specify additional reporting requirements for studies intended for third parties. Such reports must include information on the study's goal and scope (e.g., functional unit, exclusions), the LCI analysis (e.g., data collection procedures, data sources), the life cycle impact assessment (e.g., impact indicators, impact assessment method used), and the interpretation of results (e.g., assumptions, limitations). All of these elements are listed in section 5.2 of *ISO 14044*.

During the interpretation phase, the standards recommend performing several complementary analyses, such as completeness checks, sensitivity analyses, and consistency checks. For third-party reports, disclosure of the results of sensitivity analyses and data quality assessments is mandatory.

Furthermore, LCA standards establish additional requirements for comparative studies where results are publicly disclosed. These include analyses of data precision, completeness, and representativeness (see section 5.3.1 of *ISO 14044*). However, such comparisons are not permitted in O-LCA, and these specific requirements do not apply. Instead, *ISO 14072* requires the disclosure of information on structural changes that may influence the tracking of emissions over time.

While *ISO 14040/44* provides the general framework for LCA, many other standards introduce more specific reporting requirements. For example, PCRs often define a standardized reporting format for impact results, prescribe specific impact categories to assess and report, and identify elements that must be disclosed separately (e.g., avoided emissions from co-products).

11.3 Comparison of approaches – Reporting and results interpretation

In general, the **GHG Protocol is more specific regarding the quantitative and qualitative elements to include in a report.** For instance, it requires reporting emissions by individual GHGs, for each scope, and for each scope 3 category. This is to be expected, as the GHG Protocol outlines a more targeted type of study than the general LCA framework set out in *ISO 14040/44*. That said, it is not necessarily more detailed than specific LCA frameworks (e.g., PCRs).

A key difference between the two approaches lies in the **emphasis placed on result interpretation**. LCA approaches typically require more complementary analyses to better interpret results and identify their limitations (e.g., data quality assessments, sensitivity analyses, and uncertainty analyses). This reflects the fact that one of the GHG Protocol's goals is to simplify the process of conducting a GHG inventory. Reducing the need for additional analyses aligns with that objective. Conversely, *ISO 14072* explicitly requires sensitivity and data quality analyses.

Finally, another important difference is that LCA requirements vary depending on the **intended use of the report.** The level of disclosure and interpretation required is less stringent for internal reports than for those intended for third parties. LCA standards even include specific requirements for comparative studies disclosed to the public, which are generally less relevant for organizational studies, whose goal should not be to compare two different organizations.

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