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A review of standards and frameworks for reporting of biogenic CO2. Open version.

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Preface

Borregaard is a world leading biorefinery that produces biochemicals from Norway spruce (Picea abies). With increasing attention towards sustainable production and reduction of greenhouse gases, they experience increased interest in how emissions of greenhouse gases, and biogenic CO_2 in particular, of a product are calculated and how potential greenhouse gas savings can be communicated. NORSUS has therefore been commissioned by Borregaard to summarize different standards and frameworks that are relevant for Borregaard's reporting and communication of environmental information. Focus has been on CO_2, with a special emphasis on biogenic CO_2.

This report is a modified version of report OR.21.21 (Soldal and Modahl, 2021). In the current version, confidential information from Borregaard has been removed.

Contents

Glossary

Characterization factor	In LCA, emissions from production of a product or service are inventoried and classified into one or more impact categories, like climate change. When the emissions have been classified in the right impact categories, their potential effect in each impact category is quantified via characterization factors. The characterization factor relates the effect of a substance to a reference substance. For example, for climate change the reference substance is CO_2, and the potential effect on the climate of all greenhouse gases (GHG) are related to the effect of CO_2. Hence, the emissions of GHGs are given in CO_2-equivalents.
GHG	Greenhouse gas. Greenhouse gases have a warming effect on the Earth's atmosphere due to their ability to absorb energy and slow down the rate the sun's radiation are returned to space. The total effect of a GHG on the warming of the Earth, depends on how much energy the GHG absorbs and how long life time it has in the atmosphere.
GWP	Global warming potential is the quantified measure of a greenhouse gas' ability to absorb infrared radiation relative to that of CO_2, integrated over a period of time. The timeframe is usually 100 years (known as GWP100).
Indicators	In LCA emissions are grouped into different environmental indicators or impact categories. The emission of one substance can contribute to several indicators and several substances contribute to each indicator. The impact is related to a reference substance. For instance, emission that contribute to climate change are related to CO_2. Examples of indicators are climate change, acidification and eutrophication.
LCA	Life cycle assessment of a product is defined as a systematic mapping and evaluation of impacts on the environment and resource consumption throughout a defined part, or the entire life cycle, of the product. An LCA includes the environmental impacts due to raw material extraction, production, transport, use and waste management.
PCR	To be able to compare products with equal functions, specific rules, requirements, and guidelines have been developed for product categories. These are known as product category rules (PCR).
System boundaries	The system boundaries defines which processes that belong to the system you want to analyze, and includes boundaries between nature and the techosphere (i.e the technical system, man-made), and boundaries between the technical system analyzed and other technical systems (Finnveden et al., 2009), in addition to boundaries in space and time.

Abbreviations

CFP	Carbon footprint
EC-JRC	European Commission Joint Research Center
EDP	Environmental product declaration
EF	Environmental footprint
EN	European standards
ISO	International Standard Organization
LULUC	Land use and land use change
NS	Norwegian standards

1 Introduction

1.1 Standards and guidelines

Environmental sustainability and contribution to climate change are becoming increasingly important for organizations. To facilitate comparison between products and manufacturers across organizational and geographical borders, a range of standards and guidelines that regulate the quantification, reporting and communication of environmental performance in general, and specifically contribution to climate change, have been developed. Among these we find the ISO 14000-series, the Greenhouse gas Protocol, guidelines for environmental product declarations, and carbon footprint (these are further explained later in this report).

Common for these standards is that for assessment of climate change impact they are based on the work of Working Group 1 of the International Panel on Climate Change (IPCC*): Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (IPCC, 2013). In this framework, the metric Global Warming Potential (GWP) is used, and the climate impact of different greenhouse gases (GHGs) are normalized to the climate impact of CO_2. Based on the radiative efficiency (i.e. how potent greenhouse gas it is) and atmospheric lifetime of a GHG, the contribution to climate change is given relative to CO_2, in CO_2 equivalents. The GWP for a time horizon of 100 years is typically used. This means that the characterization factor for a greenhouse gas is a quantification of how much radiant energy the gas in question absorbes in a 100 year perspective, relative to that of CO_2. IPCC has also given GWP values for 20 years and 500 years. Because CO_2 is the reference gas, it always has a GWP=1, while for other GHGs the GWP will be different for different time horizons.

In this report the 100 years' time horizon is mentioned several times. In addition to the time horizon of GWP of 100 years decided by IPCC, 100 years' time horizon also refers to the lifetime of products in the Environmental Footprint system (EF) that decides if one can considered the sequestered carbon as permanent carbon storage. If the biogenic carbon is emitted more than 100 years after it has been sequestered, it can be considered permanent carbon storage according to the EF-method (see more in Chapter 2.5).

The International Organization for Standardization (ISO) have published the ISO 14000 series of standards to promote effective environmental management in organizations. Among the covered subjects in the series, we find ecolabeling, environmental product declarations (EPDs), life cycle assessment and carbon footprint (CFP), see Figure 1. The World Resource Institute (WRI) has developed the GHG Protocol together with the World Business Council for Sustainable Development (WBCSD). It provides governments, industry associations, NGOs, businesses, and other organizations with a framework for measure and manage GHG emissions.

An environmental product declaration (EPD) is a verified certificate of environmental performance of a product or material. Development of EPDs is regulated through EN-standards and ISO-standards and promotes transparency and ease of comparison between products fulfilling the same function.

The European Commission has developed the Environmental Footprint (EF) methodology. The aim is to provide a common way of measuring environmental performance within the EU and the system is still in the testing phase. The EF system is divided into Organisation Environmental Footprint (OEF) and Product Environmental Footprint (PEF).

One of the major advantages of LCA is the possibility to analyze and explore several indicators in order to avoid problem shifting (i.e. shifting from one environmental problem to another environmental problem). This opportunity is lost when performing carbon footprint and GHG reporting that only investigates the emissions of GHGs.

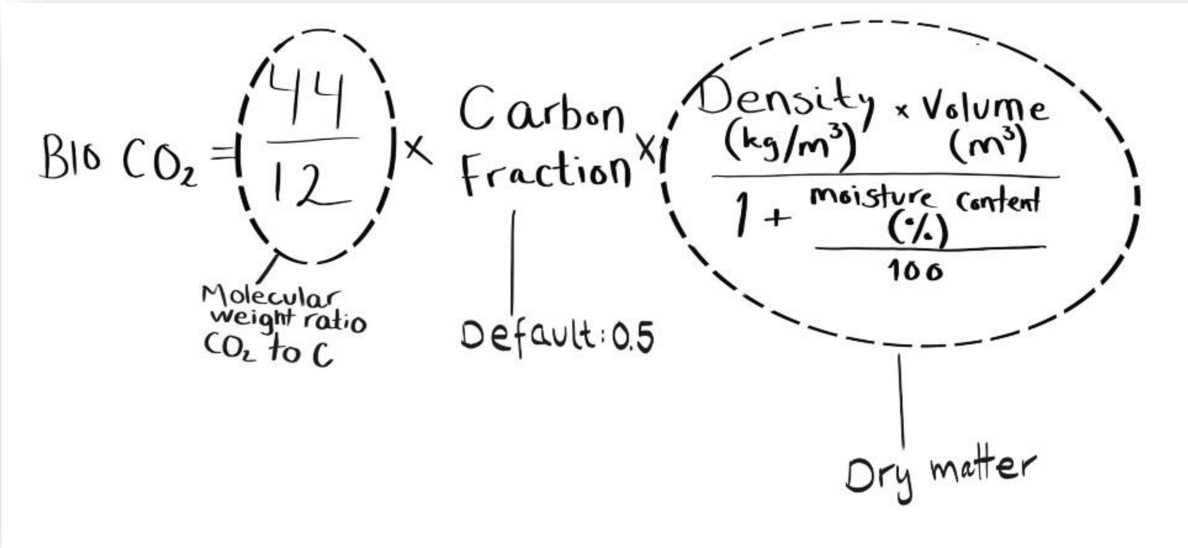
In the next chapter, the different standards and regulations will be described and compared with emphasis on how they treat biogenic carbon/biogenic CO_2 and the climate effect of land use change. Standards and guidelines that are part of a reporting or documenting framework are included. There are other standards who also treat biogenic carbon, carbon storage and land use, but they are not included here as we have focused on standards that are part of reporting framework.

In the standards the term “shall” is used to indicate what is obligatory, while “should” is used for recommendations and “may” is used to indicate what is an option. The report also has a chapter dedicated to regulations of communication of environmental information and a chapter on the substitution effect.

1.2 Biogenic carbon

Wood products contains carbon that is sequestered through photosynthesis and stored in the biomass. This is known as biogenic carbon. If the wood product is combusted or decomposed, this carbon is released to the atmosphere as biogenic CO_2. NS-EN 16449:2014 *Wood and wood-based products – Calculation of the biogenic carbon content of wood and conversion to carbon dioxide* (CEN, 2014) provides a calculation method to quantify the amount of atmospheric CO_2 based on the biogenic carbon content of biomass and wood products. The calculation is based on the atomic weights of carbon and carbon dioxide, and specific information like the carbon fraction and mass of biomass. If one does not know the carbon content of their product, the default carbon fraction of 0.5 is used (50% carbon of the dry matter content). The formula is given in Equation 1. This formula is referred to in other standards.

Equation 1 Conversion of the biogenic carbon (kg C) to carbon dioxide (kg CO_2) (CEN, 2014). If the carbon content of the wood product is unknown, the default fraction of 0.5 is used.



Carbon stocks represent the quantity of carbon stored in different pools, including soil, biomass and harvested wood products. An increase in carbon stocks is a biogenic carbon removal from the atmosphere, and a decrease in carbon stocks is a biogenic carbon emission to the atmosphere in the form of CO_2.

Borregaard's products are well analyzed, and the carbon content is known. Equation 1 can be applied to Borregaard's products to calculate the CO_2-emissions resulting from the content of biogenic carbon (Table 1). Biogenic CO_2 will be emitted if the products are combusted or decomposed.

Table 1 Calculation to quantify the amount of atmospheric carbon dioxide based on the biogenic carbon content of wood-based products from Borregaard. The calculations are based on Equation 1 (NS-EN 16449:2014).

Product	Formula	Carbon fraction	Molecular weight ratio C to CO2	kg CO2 per kg dry matter
Lignosulfonat CAS 8061-52-7	$C_{20}H_{24}CaO_{10}S_2$	0.45	3.67	1.67
Xylose, non fermentable sugars	$C_5H_{10}O_5$	0.40	3.67	1.47
Glucose, fermenatble sugars	$C_6H_{12}O_6$	0.40	3.67	1.47
Vanilin	$C_8H_8O_3$	0.63	3.67	2.32
Cellulose	$C_6H_{10}O_5$	0.44	3.67	1.63
EtOH	C_2H_6O	0.52	3.67	1.91
Wood		0.50	3.67	1.85

1.3 Land use and land use change

When the use of a land area leads to a change in the amount of biomass above and below ground this will lead to a change in the carbon stock through increased CO_2 emissions or increased uptake of CO_2 in the ground. For instance, a change from forest to agricultural land will lead to increased emissions of CO_2 as a forest contains more carbon both below and above ground than agricultural land. This is referred to as land use and land use change.

Direct land use change (LUC) is change in the human use of the land within the boundaries of the system under study. Indirect land use change (iLUC), on the other hand, is land use change that takes place outside our product system.

In addition to the climate impact of LULUC, land use related impacts can be covered by the indicator Potential Soil quality index. However, as mentioned, in this document we will only look at the impact on climate.

1.4 Report structure

In Chapter 2, two figures and two tables are shown first in order to illustrate how the different standards are related to each other, together with the differences in function, system boundaries and indicators used in each system, and characterization factors used for CO_2. A summary of the standards follows after that. Chapter 3 contains a discussion on communication of environmental information and Chapter 4 describes different ways of calculating substitution effects.

2 Standards summarized

The standards and frameworks that are included in this report differ or coincide in mainly three dimensions:

1. Function: analysis on product or organizational level (Figure 1).
2. System boundaries: which life cycle phases of the product(s) or organization are included (Figure 2).
3. Indicators: which environmental indicators are assessed (Table 2).

In addition, the standards and frameworks differ in how/if they give a characterization factor for CO_2 emissions, both fossil and biogenic (Table 3).

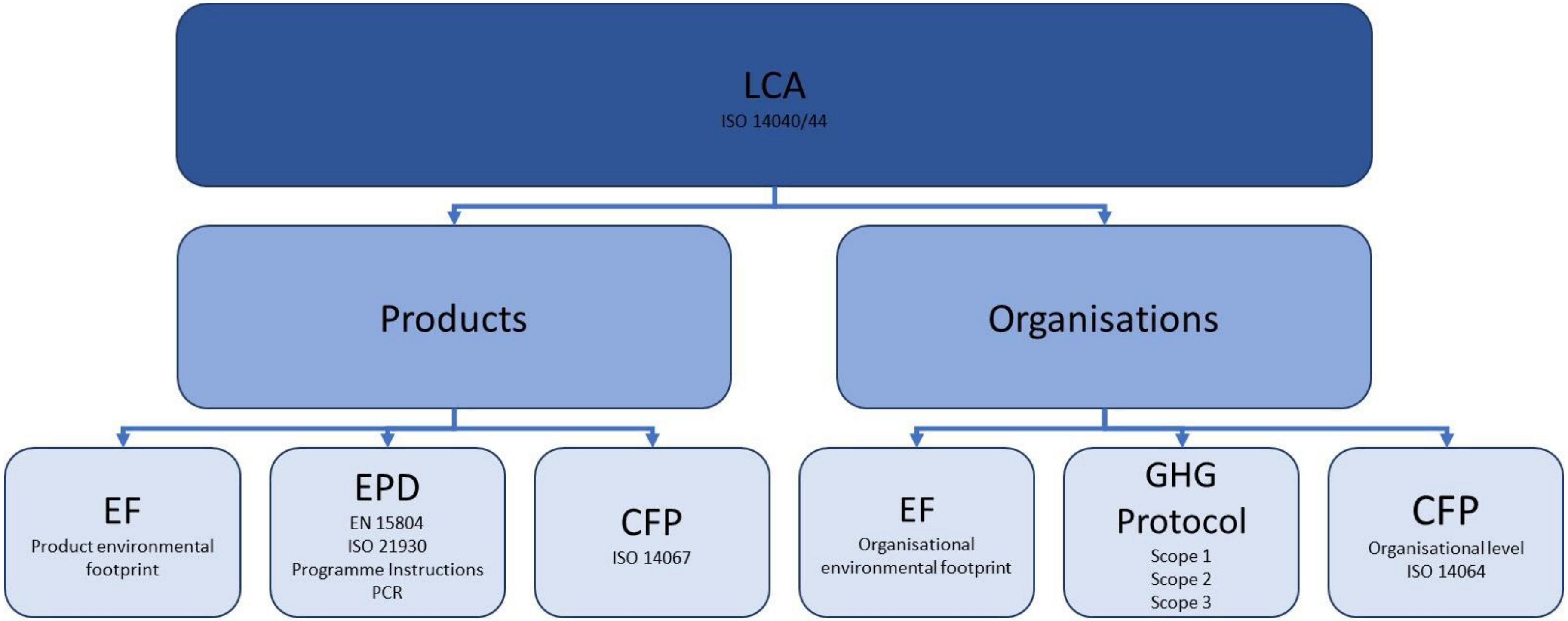


Figure 1 The flow sheet illustrates how the different standards and frameworks relates to the *function* (product or organizational level).

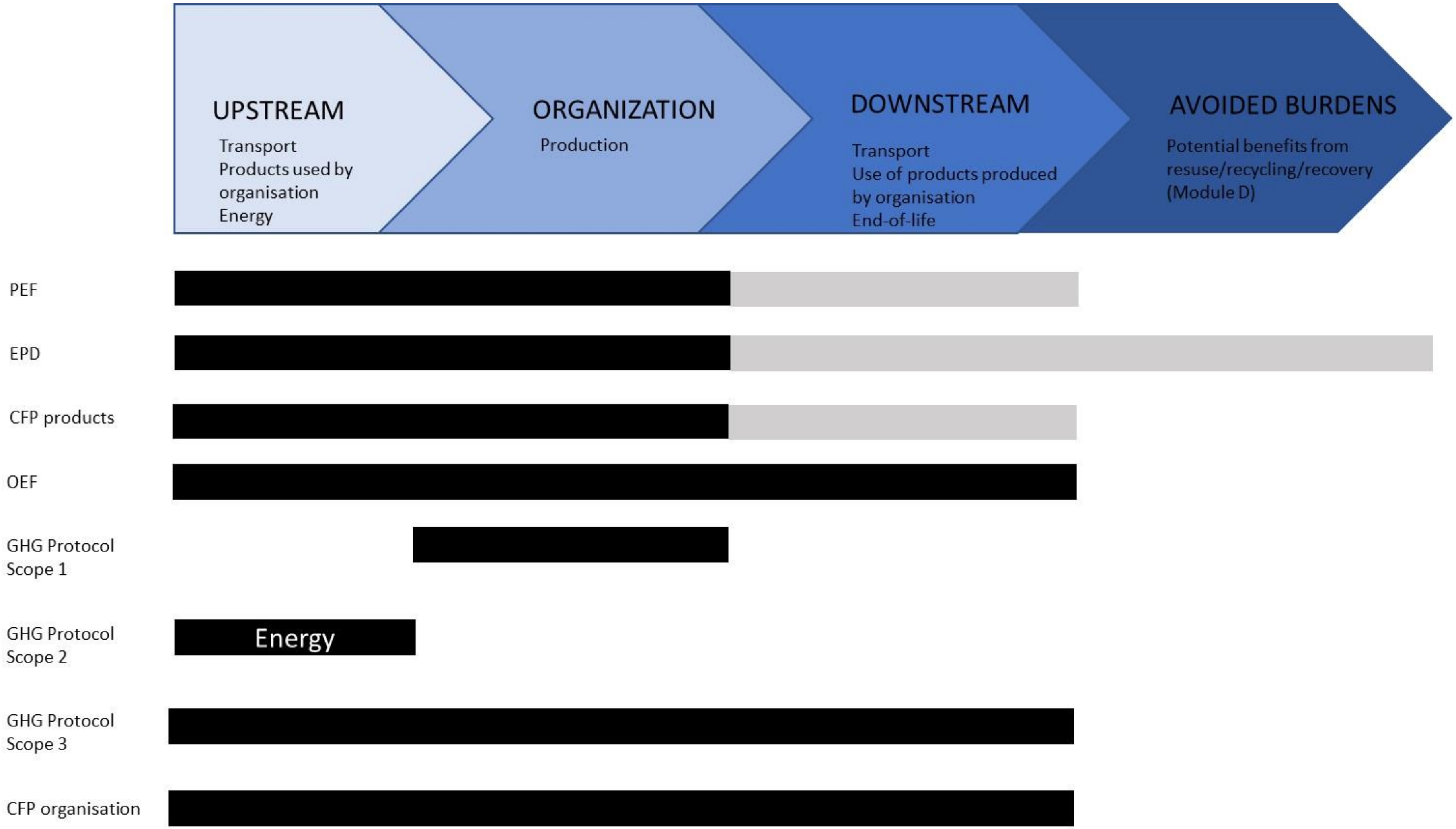


Figure 2 Illustration of how the different standards and frameworks relates to the *system boundaries* (life cycle phases). Solid black symbolizes mandatory life cycle phases, while grey illustrates optional life cycle phases.

Table 2 Summary table showing function, system boundaries and indicators in focus in the different standards and frameworks. In addition, rules for treatment of biogenic carbon and land use impact on climate are given. If the subject is not mentioned in the standard, it is indicated with the symbol '-'. Standards applied in work committed by NORSUS on Borregaard products are marked with *

	Name	Function	System boundaries	Indicators	Biogenic CO_2				Land use effect on climate
					Removals from air	Emissions	Carbon storage in product	Carbon content in products	
LCA	**ISO 14040*** Environmental management — Life cycle assessment — Principles and framework **ISO 14044*** Environmental management - Life cycle assessment - Requirements and guidelines	Products (functional unit)	Ideally all processes from input from nature to output to nature.	Not defined	-	-	-	-	-
EPD	**EN15804:2012 + A2:2019** Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.	Products (functional or declared unit)	Ideally all processes. Separated into modules A1-A3 with options A4-A5, C1-C4 and D.	Core indicators: Climate change (4 subcategories), ozone depletion, acidification, eutrophication freshwater, marine and terrestrial, photochemical oxidant formation, depletion of abiotic resources minerals and metals, and fossil fuels, and water use.	Characterized (-1 kg CO_2-eqv/kg CO_2)	Characterized (+1 kg CO_2-eqv/kg CO_2)	Shall not be included	Yes, carbon content of product and packaging shall de declared.	Yes

	Name	Function	System boundaries	Indicators	Biogenic CO_2				Land use effect on climate
					Removals from air	Emissions	Carbon storage in product	Carbon content in products	
EPD	**ISO 21930** Sustainability in buildings and civil engineering works - Core rules for environmental product declarations of construction products and services	Products (functional or declared unit)	Ideally all processes. Separated into modules A1-A3 with options A4-A5, C1-C4 and D.	Mandatory impact categories: GWP, ozone depletion, eutrophication, acidification, photochemical oxidant formation.	Characterized (-1 kg CO_2-eqv/kg CO_2)	Characterized (+1 kg CO_2-eqv/kg CO_2)	Shall not be included	Yes, carbon content of product and packaging shall be declared.	When significant
EPD	Program instructions EPD-Norway (2019)*	Products (functional or declared unit)	As defined in ISO 14044	As defined in EN 15804:2012+A1:2013: Climate change, depletion of stratospheric ozone, acidification, eutrophication, formation of tropospheric photochemical oxidants, depletion of abiotic resources, depletion of abiotic fossil resources.	-	-	-	-	-
EPD	PCR (Basic chemicals)	Products (functional or declared unit)	Ideally all processes. Separated into modules A1-A3 with options A4-A5, C1-C4 and D.	Climate change (4 subcategories), acidification, eutrophication, photochemical oxidant formation, depletion of abiotic resources (elements and fossil fuels) and water scarcity.	-	-	-	-	-

	Name	Function	System boundaries	Indicators	Biogenic CO_2				Land use effect on climate
					Removals from air	Emissions	Carbon storage in product	Carbon content in products	
	PCR (Basic organic chemicals) *[1]	Products (functional or declared unit)	Ideally all processes. Separated into modules A1-A3 with options A4-A5, C1-C4 and D.	Climate change (4 subcategories), acidification, eutrophication, photochemical oxidant formation, depletion of abiotic resources (elements and fossil fuels) and water scarcity.	-	-	-	-	-
Carbon footprint	**ISO 14064** Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals	Organization, reporting period (for example 1 year).	Ideally all processes. Separated into direct and indirect emissions and removals; upstream, current production and downstream.	Climate change (separate between non-biogenic and biogenic emissions in the reporting).	Shall be quantified.	Shall be quantified.	Carbon storage in goods, should be treated as in ISO 14067.	Can be declared in the report.	GHG emissions and removals due to land use change occurring within the last 20 year shall be included in the CFP. GHG emissions and removals due to land use should be included.
	ISO 14067 Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification	Products (functional or declared unit)	According to goal and scope of the study: separation into upstream, current production and downstream.	Climate change (separate between non-biogenic and biogenic emissions.	Characterized (-1 kg CO_2-eqv/kg CO_2)	Characterized (+1 kg CO_2-eqv/kg CO_2)	Can be declared in the report (not part of CFP)	Can be declared in the report (not part of CFP)	GHG emissions and removals due to land use change occurring within the last 20 year shall be included in the CFP. GHG emissions and removals due to land use

[1] The PCR is used in conjunction with the EPD-template and instructions from EPD-Norway. Hence, not all indicators are the same as defined in the PCR.

	Name	Function	System boundaries	Indicators	Biogenic CO_2				Land use effect on climate
					Removals from air	Emissions	Carbon storage in product	Carbon content in products	
									should be included.
GHG protocol	Scope 1 GHG Protocol	Organization – 1 operating year	Direct emissions from facility.	Climate change (six Kyoto gases[2])	Not included in calculations of the scope but may be reported separately.	Not included in calculations of the scope but reported separately.	-	-	-
	Scope 2 GHG Protocol	Organization – 1 operating year	Indirect emissions for facility in question; from production of electricity, heat, steam and cooling.	Climate change (six Kyoto gases[1])	Not included in calculations of the scope but may be reported separately.	Not included in calculations of the scope but reported separately.	-	-	-

[2] Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and the so-called F-gases (hydrofluorocarbons and perfluorocarbons) and sulphur hexafluoride (SF6).

	Name	Function	System boundaries	Indicators	Biogenic CO_2				Land use effect on climate
					Removals from air	Emissions	Carbon storage in product	Carbon content in products	
GHG protocol	Scope 3 GHG Protocol*	Organization – 1 operating year	Ideally all processes. Separated into direct and indirect emissions; upstream, from facility and downstream.	Climate change (separate between non-biogenic and biogenic emissions).	Not included in calculations of the scope but may be reported separately.	Not included in calculations of the scope but may be reported separately.	**-**	Carbon content of products reported, facilitating reporting for downstream processes.	**-**
Environmental Footprint	**PEF** PEFCR Guidance document, - Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3	Products (functional unit)	All stages from raw material acquisition and pre-processing, production of the main product, product distribution and storage, use stage and end of life treatment of the product (if appropriate)	Climate change, total (3 subcategories), Ozone depletion, Human toxicity, cancer, Human toxicity, non-cancer, Particulate matter, Ionising radiation, human health, Photochemical ozone formation, human health, Acidification, Eutrophication, terrestrail, Eutrophication, freshwater, Eutrophication, marine, Ecotoxicity, freshwater, Land use, Water use, Resources use, minerals and metals, Resources use, fossils. Not all impact categories are mandatory.	Yes, if carbon stored >100 years	Reported, but not characterized.	If storage time >100 years.	Yes	Uptake and emissions of CO_2, CO and CH_4 due to changes in carbon stock caused by direct land use and land use change within the last 20 years, or the last harvest period, prior to undertaking the assessment (whichever is the longer).

Name	Function	System boundaries	Indicators	Biogenic CO_2				Land use effect on climate
				Removals from air	Emissions	Carbon storage in product	Carbon content in products	
OEF OEFSR Guidance document, - Guidance for the development of Organisation Environmental Footprint Sector Rules (OEFSRs), version 6.3	Organization – 1 operating year	Products/ services included in the product portfolio, including all stages from raw material acquisition and pre-processing, production, distribution and storage, use stage and end of life	Climate change, total (3 subcategories), Ozone depletion, Human toxicity, cancer, Human toxicity, non-cancer, Particulate matter, Ionising radiation, human health, Photochemical ozone formation, human health, Acidification, Eutrophication, terrestrail, Eutrophication, freshwater, Eutrophication, marine, Ecotoxicity, freshwater, Land use, Water use, Resources use, minerals and metals, Resources use, fossils.	Yes, if carbon stored >100 years	Reported, but not characterized.	If storage time >100 years.	Yes	Uptake and emissions of CO_2, CO and CH_4 due to changes in carbon stock caused by direct land use and land use change within the last 20 years, or the last harvest period, prior to undertaking the assessment (whichever is the longer).

Table 3 Characterization factor for CO_2 given in standards and guidelines.

		Characterization factors (kg CO_2-eqv/kg CO_2)			LULUC	
Standard/guideline	Indicator	CO_2 - removals	Biogenic CO_2 - emissions	Fossil CO_2 - emissions	CO_2 from soil	CO_2 to soil
EPD-Norway/IPCC 2013 GWP100a, v.1.03	Climate change	0	0	1	1	-1
EN 15804:2013 + A2:2019	Climate change - fossil	-	-	1	-	-
	Climate change - Biogenic	-1	1	-	-	-
	Climate change - Land use and LU change	-	-	-	1	-1
	Climate change - total	-1	1	1	1	-1
ISO 21930	Climate change	-1	1	1	-	-
ISO 14067	Carbon footprint	-1	1	1	-	-
GHG Protocol	Fossil CO_2-eq.	-	-	1	-	-
	Biogenic CO_2-eq.[3]	1	1	-	1	1
PEFCR Guidelines	Climate change - fossil	-	-	1	-	-
	Climate change - Biogenic	0	0	-	-	-
	Climate change - Biogenic >100 years[4]	-1	0	-	-	-
	Climate change - Land use and LU change	-	-	-	1	-1

[3] Not characterized as negative emissions but accounted for and shown separately.
[4] Biogenic carbon emitted later than 100 years after uptake.

2.1 Life cycle assessment – ISO 14040/44

Life cycle assessment (LCA) is a systematic mapping and evaluation of impacts on the environment and resource consumption throughout a defined part, or the entire life cycle, of a product system. An LCA includes the environmental impacts due to raw material extraction, production, transport, use and waste management (Baumann and Tillman, 2004). LCA is standardized through the ISO-standards *ISO 14040 Environmental management — Life cycle assessment — Principles and framework* and *ISO 14044 Environmental management - Life cycle assessment - Requirements and guidelines* (ISO, 2006a, ISO, 2006b). These standards describe the principles and framework for LCA including definitions of the goal and scope, data quality, the life cycle inventory analysis (LCI), the life cycle impact assessment (LCIA) and the life cycle interpretation phase. They also regulate reporting and critical review of the LCA results. These two standards form a basis for LCA-studies and for other standards and frameworks. One of the main reasons for applying LCA is to avoid so-called problem shifting. For instance, if one only considers the production stage of products, one might favor products with large environmental impacts in the use or end-of-life stages. Similarly, if one only focuses on a single environmental impact, like climate change, one may favor products with poor performance in other environmental impact categories like local air pollution or toxicity. With the aid of LCA, such possibilities of problem shifting may be identified and addressed.

LCA can be used for different purposes, such as comparing different products or services that fulfil the same function, identifying opportunities for improvement in a production system, and as decision support (Baumann and Tillman, 2004).

ISO 14040/44 gives a framework for performing LCA and defines important expressions and terms used. However, because there are so many possible uses of an LCA, the method needs to be flexible, and at the same time rigid enough to facilitate comparisons. Due to the variable use of LCA, ISO 14040/44 does not describe which impact categories that shall be included, only that the impact categories and impact assessment models should be internationally accepted. ISO 14040/44 does therefore not include any information on how to treat biogenic CO_2 or land use and land use change (LULUC). The selection of impact categories, indicators and characterization models needs to be justified in each case, based on the goal and scope of the study. Therefore, product category rules (PCR) and guidelines have been created to provide specific rules for what should be included in different applications.

2.2 Environmental Product Declaration (EPD)

An EPD is a verified certificate that communicates environmental performance of a product or group of products. The assessment of environmental performance is based on LCA, and ISO 14040/44 are fundamental standards for development of EPDs. In addition, development of EPDs is regulated by:

- EN 15804: Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products (CEN, 2019).
- ISO 21930: Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services (ISO, 2017b).
- Program instructions and product category rules (PCR): product specific set of specific rules, requirements, and guidelines for developing Type III environmental declarations.

Use of EPDs have been most widespread in the construction sector. Hence, several standards and guidelines are customized to construction products, but still, they form the fundament for EPDs for other products also. In addition, intermediate products that goes in to building products should follow the same standards as the building product for facilitating inclusion of the environmental information in EPDs for the building products.

2.2.1 EN 15804:2012+A2:2019

EN 15804 is the core PCR for Type III environmental declarations for any construction product and service (CEN, 2019). It is also seen as the main reference for EPD programs (Durão et al., 2020) and defines several of the rules that are common for all EPDs. Unlike a carbon footprint analysis, an EPD asses several impact categories. EN 15804 defines that the characterization factors from EC-JRC shall be applied. For climate impact, the latest version of the IPCC characterization factors shall be used.

In the 2019-edition of EN 15804, one of the changes from the 2013-edition is the requirement to divide the climate change impact category into three parts: GWP fossil, GWP biogenic and GWP LULUC, and these are summarized to GWP total. In the previous version (2013) biogenic CO_2 and land use were not specified.

According to EN 15804, EPDs shall follow the modularity principle, and declare result for several modules:

A1- A3: raw materials, transport, and production;
A4: transport to the building site or central warehouse;
A5: installation into the building;
B1-B5: use stage, maintenance, repair, replacement, and refurbishment;
B6-B7: operational energy use and operational water use;
C1-C4: deconstruction, transport to waste processing, waste processing and disposal;
D: benefits and loads beyond the system boundary – reuse, recycling potential, expressed as net impacts and benefits.

Different types of EPDs can be developed, depending on which of the modules are included:

- Cradle-to-gate
  - with A1-A3. This is the minimum and is based on a declared unit.
  - with options – includes A1-A3 and additional modules that may be A4 and/or A5. Based on functional or declared unit.
  - with modules C1-C4 and D: includes A1-A3, C and D. This is default minimum and is based on a declared unit.
  - with options: modules A1-A3, C and D, and additional modules (A4-A5, B). Declared unit or functional unit if B-modules are included.
- Cradle-to-grave and module D. Based on functional or declared unit.

Products containing biogenic carbon, must declare modules C1-C4 and D, in addition to A1-A3. For these products, the carbon content of the product and packaging shall be declared. Exception is made when the carbon content is <5%. In those cases, declaration of the carbon content can be omitted. Declarations of carbon content can be calculated or measured. The following shall not be included in the calculations of GWP:

1. Carbon offset (reduction in emissions of GHG in another product system in order to compensate for GHG emissions).
2. Effect of temporary carbon storage and delayed emissions.
3. The effect of permanent biogenic carbon storage.

Calculation of climate change impact category:

1. GWP total: sum of the sub-categories.
2. GWP fossil: emissions and removals of GHG due to oxidation or reduction of fossil fuels or materials containing fossil carbon. Peat is per definition fossil carbon in this context.
3. GWP biogenic: emissions and removals of CO_2 into biomass from all sources, except from native forest. This includes transfer of carbon from nature into the product system, from previous product system to current product system, from product system to subsequent product systems. The amount of CO_2 taken up in biomass is equal to the amount of biogenic CO_2 emitted.
4. GWP LULUC: emissions and removals of GHG originating from changes in the defined carbon stocks caused by land use and land use change. Follow the latest PEF Guidance document (PEF=product environmental footprint). For native forest, all emissions of CO_2 are included as emissions due to land use change, while the uptake of CO_2 in native forest is set to zero. Native forest excludes managed forest and forest with short-term or long-term rotation periods.

The impacts are declared in the module they occur. Removal of CO2 by growing biomass: -1 kg CO_2 eqv/kg CO_2 when entering the system. Emissions of biogenic CO_2: +1 kg CO_2-eqv/kg CO_2.

2.2.2 ISO 21930:2017

ISO 21930:2017 *Sustainability in buildings and civil engineering works - Core rules for environmental product declarations of construction products and services* (ISO, 2017b) provides principles, specifications and requirements to develop an environmental product declaration (EPD) for construction products and services, construction elements and integrated technical systems used in any type of construction works. Regarding accounting of biogenic carbon, this standard state that flow of carbon to and from nature, and between product systems shall be reported in this manner:

- Flow of biogenic carbon from nature to technosphere -1 kg CO_2-eqv/kg CO_2
- Flow of biogenic carbon from technosphere +1 kg CO_2-eqv/kg CO_2
- Flow of biogenic carbon between product systems:
  - -1 kg CO_2-eqv/kg CO_2 when entering the current production system.
  - +1 kg CO_2-eqv/kg CO_2 when leaving the current production system.

This is only valid when the wood biomass originates from sustainable managed forests. Through the whole life cycle (A1-C4) this gives a zero-net contribution to GWP except when carbon is converted to CH_4. Wood from sustainable managed forests may be declared with zero emissions due to LUC.

2.2.3 PCR: Basic chemicals

For the products from Borregaard, the PCR for basic chemicals is considered to be best suited for future analyses. This PCR is being updated and replace PCR for Basic organic chemicals that has been used for the Borregaard EPDs in 2016 and 2021. This PCR has just been published and is available for downloading at www.environdec.com. The PCR for Basic organic chemicals was selected because it was the best available PCR at the time of making the EPDs. In addition, this PCR is produced for organic chemicals and can be applied to all the Borregaard products that EPDs are being develop for. This ensures consistency in the analysis between the different products.

See www.environdec.com for draft and progress in publication. www.environdec.com is the webpage of the International EPD system. The PCR Basic chemicals builds on ISO 14040 and ISO 14044. For impact assessment categories and methods, the PCR refer the reader to www.environdec.com. On www.enviorndec.com we find that for climate impact, the latest version of the characterization factors from IPCC shall be used. The climate impact is divided into GWP fossil, GWP biogenic, GWP LULUC and GWP total.

2.3 Climate footprint

2.3.1 ISO 14064-1:2018

ISO 14064-1:2018 *Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals* (ISO, 2018a) is the generic standard for quantification and reporting of greenhouse gas emission and removal at an organizational level. In the standard you can find principles for developing and reporting organizational-level GHG inventories as well as requirements for system boundaries and quantification of GHG emissions and removals.

An organization is defined as “a person or people that has its own functions with responsibilities, authorities and relationships to achieve its objectives.” This includes, but is not limited to, companies, firms, partnerships, and institutions. The operational borders are defined by the organization itself and that is based on the concepts of equity share and control. If the Control consolidation approach is applied, the organization accounts for all GHG emissions and removals from facilities over which it has operational control, i.e. 100% of the emissions. If the Equity share consolidation approach is applied, the organization accounts for its portion of the GHG emissions and removals, i.e. % of economic interest. The organization can report optional information on carbon offsets. The reporting is done for a selected time period.

ISO 14064-1 separates between anthropogenic and non-anthropogenic biogenic CO_2 emissions. Anthropogenic biogenic CO_2 emissions are emissions of GHG from biological material as a result of human activities, while non-anthropogenic CO_2 emissions are emissions of GHG from biological material that are caused by natural processes (wildfires, decomposition etc.).

Regarding the GHG inventory categories, the GHG emissions shall be aggregated into the following categories:

1. **Direct emissions and removals**

   Direct GHG emissions and removals occur from GHG sources or sinks inside organizational boundaries and that are owned or controlled by the organization. This includes emissions from combustion, fugitive emissions, process emissions and emissions/removals due to land use, land use change and forestry.

2. **Indirect GHG emissions from**
   a. Imported energy: indirect emissions from production and consumption of electricity and steam, heat, cooling.
   b. Transportation: emissions from production and consumption of fuel, refrigeration gas leaks and production of transport equipment not owned by the organization.
   c. Products used by the organization: indirect emissions linked to consumer goods and capital good used by the organization. Emissions due to extraction of raw materials, manufacturing, and processing of materials.
   d. Services used by the organization: emissions linked to services used by the organization from sources located outside the organization. Waste treatment is an example of this.
   e. Use of products from the organization: GHG emissions and removals associated with the use of the products sold by the organization, occurring after the organization's production process. When the organization do not know the exact destiny of the product, plausible scenarios should be defined, and clearly stated in the report.
   f. Other sources.

In each of these categories, non-anthropogenic biogenic CO_2-emissions and removals shall be quantified and reported separately from other anthropogenic GHG-emissions. This is true only for biogenic CO_2, as other biogenic emissions, for instance of CH_4 and N_2O, shall be quantified and reported as anthropogenic emissions, with the corresponding characterization factor. For all GHG emissions, the latest GWP 100 years characterization factor from the IPCC shall be used. When carbon is stored in products for a specific time, the carbon storage should be treated according to ISO 14067 (see Chapter 2.3.2).

ISO 14064-1 contains an annex with guidance for agriculture and forestry (Annex G Agriculture and Forestry). In the IPCC guidelines, six land-use categories are listed (forest land, cropland, grassland, wetland, settlement, and other land). When the land use change from one category to another, an increase or decrease in carbon stock can take place. A decrease in the carbon stock results in emissions of GHG, while an increase in carbon stock result in removals of GHG. The emissions taking place because of an operation that reduces the carbon stock, occur after the intervention. A time period of 20 years has been defined for the finalizing of carbon stock changes after the intervention. This means that organizations quantify the total changes in carbon stock, and report them, either one time for the 20 years or as annual emissions (=1/20 of total carbon stock changes). The changes to carbon stock can be quantified using data on stock size at two points in time or by net balance of emissions and removals. To convert carbon to CO_2, multiply the carbon mass with 44/12, which is the ratio of molecular weights of CO_2 and elemental carbon (Equation 1).

ISO 14064 and the Greenhouse gas Protocol are harmonized.

2.3.2 ISO 14067: 2018:

ISO 14067: 2018: *Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification* (ISO, 2018b) is the generic standard for quantification of carbon footprint of products, in accordance with ISO 14040/44.

In ISO 14067, carbon footprint of a product (CFP) is defined as the sum of GHG emissions and GHG removals in a particular product system, expressed as CO_2-equivalents. It is based on LCA, connected to the definition of product systems. Unlike GHG reporting for organizations, a CFP study is structured around a functional unit for CFP and a declared unit for partial CFP. A functional unit is a quantified performance of the product system which is used as a reference that all input and output data shall be related to. A declared unit is a quantity of a product used as a quantification of partial CFP. A partial CFP is the sum of GHG emissions and removals for one or more stages in the product life cycle. CFP includes processes in the product system; thus, carbon offsetting is not allowed in the quantification.

If a relevant PCR or CFP-PCR exists, it should be used. PCRs are also used when developing environmental product declarations (EPD), and they are conforming to ISO 14044.

All GHG emissions and removals shall be calculated as if released or removed at the beginning of the assessment period, except if the emissions from the user or end-of-life phase occurs more than 10 years after the product has been brought into use. In that case, the timing of emissions and removals relative to the year of production shall be specified.

The biogenic and fossil GHG emissions and removals shall be included and documented separately. For biomass-derived products, all relevant unit processes shall be included. This includes processes like cultivation and harvesting of biomass. A unit process is the smallest element considered in the life cycle inventory for which input and output data are considered. A product system is made up of a collection of unit processes. When defining the system boundaries for a study, one decides which unit processes that shall be included in the study.

Because the amount of biogenic CO_2 removed and emitted are identical, this results in a net zero GHG emission/removal. According to ISO 14067, biogenic carbon content of the products, if calculated, shall be documented in the CFP-report, but it shall not be included in the CFP results.

For the impact assessment, the standard states that the latest 100-year GWP given by the IPCC shall be used.

Removals of CO_2 into growing biomass shall be characterized as -1 kg CO_2-eqv./kg CO_2 when entering the product system, while emissions of biogenic CO_2 shall be characterized as +1 kg CO_2-eqv./kg CO_2. The net value of these two (removal and emissions) is zero, except for carbon converted to CH_4 or other GHGs. For CH_4 and other GHGs, the characterization factor from IPCC shall be used.

If the product system of interest has caused changes in land use that leads to an increase or decrease in carbon stock relative to a reference land use during the last 20 years, these changes shall be documented and included in the CFP. In ISO 14067 carbon stock refers to soil carbon, and carbon on below- and above-ground biomass.

In the same way as changes in carbon stock can occur due to changes in land use, this can also happen as a result of land use without changing the land use from one category to another, i.e., a forest can remain forest, but alteration of management can result in changes in carbon stock. Among activities that result in removals and emissions of GHG, we find forest establishment, harvest and construction of forest roads. These changes should be assessed and included in the CFP. Omissions of this shall be justified.

Assessment of land use and land use change shall be performed in accordance with internationally recognized methods, like the IPCC Guidelines for National Greenhouse Gas Inventories. For both land use and land use change, the net changes in carbon stock shall be calculated over the selected time period, and the time period shall include, at a minimum, one full rotation. It is stated in ISO 14067 that "wood from forest land that remains forest land has zero emissions from LUC". That means that if forest is regrown after harvest, no emissions of GHG due to LUC shall be included. Indirect land use change shall be included when an internationally agreed methodology for assessing this exists (does not exist as of April 2021).

2.4 Greenhouse gas protocol

The Greenhouse gas protocol is an international recognized framework to measure and manage greenhouse gas emissions from a variety of organizations, both private and public (WRI/WBCSD, 2013, WRI/WBCSD, 2011, WRI/WBCSD, WRI/WBCSD, 2015). Businesses report GHG-emissions within defined operational borders and per operating year. The requirements in the GHG protocol are aligned with ISO 14064.

The GHG protocol is focused on the six GHGs listed in the Kyoto Protocol are carbon dioxide (CO_2); methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); and sulphur hexafluoride (SF6). Emissions and sequestration of biogenic CO_2 shall be reported separately from the GHG reporting.

The GHG protocol divide the life cycle emission of climate gases into three different scopes:

- Scope 1 emissions: direct emissions of GHG from own operation (mobile and stationary combustion of fuel, fugitive emissions, agriculture and chemical processes).
- Scope 2 emissions: indirect emissions of GHG due to production of electricity, steam, heat and cooling purchased or otherwise acquired by the reporting company.
- Scope 3 emissions: all other indirect emissions that occur in a company's value chain. This includes emissions from upstream suppliers of energy carriers and other raw materials, as well as emissions connected to the use of the product downstream of the company.

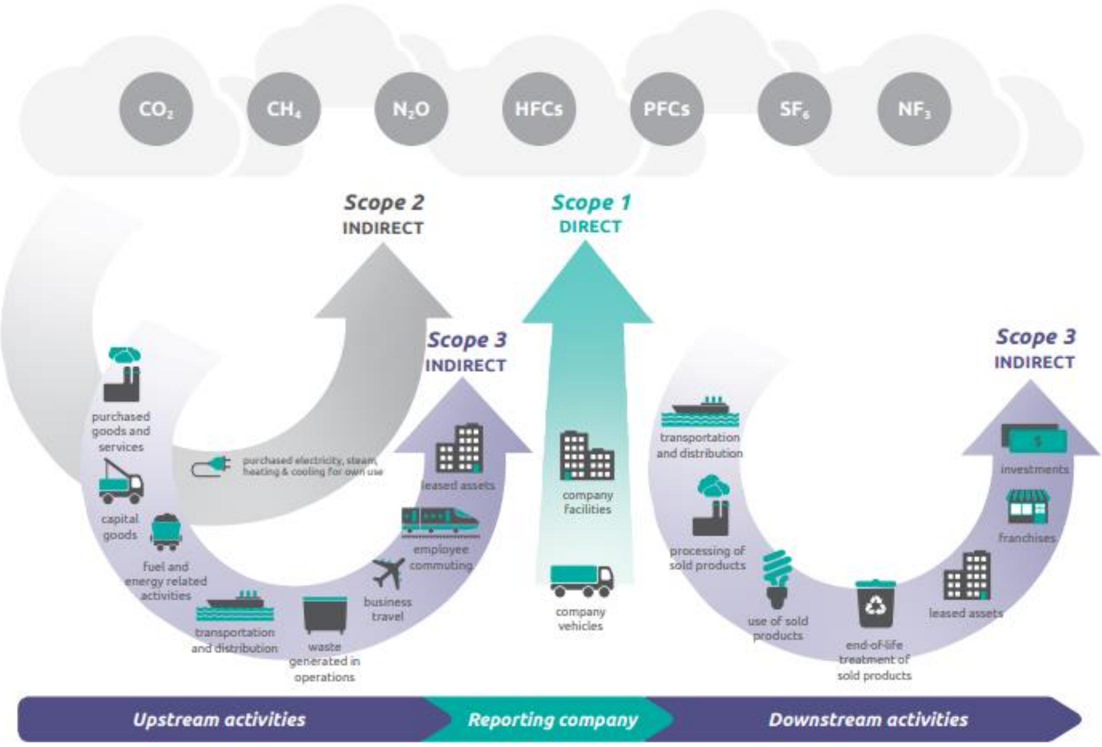


Figure 3 Overview of GHG Protocol scopes and emissions across the value chain (WRI/WBCSD, 2013).

Emissions of biogenic CO_2 that occur in the reporting company's value chain shall be reported separately from the fossil GHG emissions. Removals if CO_2 shall not be included in Scope 3 but may be reported separately.

In GHG reporting according to the GHG Protocol, information on carbon offset can be specified. This applies to both carbon offsets that have been purchased outside the inventory boundary and reductions inside the inventory boundary that have been sold or otherwise transferred to a third party.

2.5 Environmental Footprint

Environmental Footprint (EF) is a methodology developed by the European Commission, and the methodology is still in the testing phase. The development of this method started back in 2011, and in 2018, the pilot phase was finished. The EF method is now in a transition phase. This is the period between the pilot phase and the adoption of policies regarding product and organization environmental footprinting. The methodology is based on LCA and the goal is to provide a common way of measuring environmental performance within the EU. The European Green Deal will use EF metrics. Definitions and terminology in the EF system are aligned to ISO 14040/44.

The EF system is divided into Organisation Environmental Footprint (OEF) and Product Environmental Footprint (PEF). OEF has been developed to facilitate the environmental impacts of organizations. For these analyses, Organisation Environmental Footprint Sector Rules (OEFSR) have been developed. Sector-specific, lifecycle-based rules that complement general methodological guidance for OEF studies by providing further specification at the level of a specific sector. For the time being, the only sectors that have OEFSR developed are copper production and retail. Organisation environmental footprint sector rules guidance (European Comission, 2018a) provides instructions on how to develop OEFSR.

The impact category climate change is divided into *Climate change, fossil*, *Climate change, biogenic* and *Climate change, land use and land use change*. However, currently biogenic CO_2 is characterized as zero except for in the category land use and land use change, where emissions of biogenic CO_2 is characterized with +1 kg CO_2-eqv./kg biogenic CO_2 and CO_2 uptake in soil or biomass is characterized as -1 kg CO_2-eqv./kg biogenic CO_2. However, in 2019 *Suggestions for updating the organization environmental footprint method* was published by Joint Research Center and it is suggested that uptake and emissions of biogenic CO_2 is included in the category *Climate change, biogenic CO_2* as well.

PEF is for analysis of environmental impact of products (goods or services), and for a range of products Product Environmental Footprint Category Rules (PEFCR) have been developed (https://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm). All the PEFCRs are developed in accordance with *PEFCR Guidance document, - Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs), version 6.3, May 2018* (European Comission, 2018b). This document provides instructions on how to develop PEFCR in the future, and thus, information on how this document treats biogenic CO_2 and carbon storage is included in this review. If one wants to perform a PEF study of products which do not fall within the scope of a valid PEFCR, the PEF method document provides requirements.

In the guidance document for development of PEFCR, the indicator Climate change is divided into the sub-categories *Climate change, fossil*, *Climate change, biogenic* and *Climate change, land use and land use change*. The global warming potential (GWP) of CO_2, CH_4 and CO shall follow the Fifth assessment report of IPCC (2013), including climate-change carbon feedbacks for both CO_2 and non-CO_2 substances.

The sub-category *Climate change – biogenic* includes emissions and uptake of CO_2 from/to biomass. However, only methane emissions are defined as influencing climate change, and in a simplified modeling approach only the emissions of biogenic methane are included (not emissions of biogenic CO_2). If the emissions and sequestration of biogenic CO_2 are included, these have a characterization factor of zero.

Biogenic carbon emitted later than 100 years after uptake, is considered as permanent carbon storage. In the PEFCR, carbon storage time starts from the moment the carbon is taken up by the growing biomass through photosynthesis and lasts till the carbon is emitted back to the atmosphere as CO_2 through incineration or degradation. For products with a lifetime of more than 100 years, carbon credits shall be modelled as X kg CO_2-equivalents emissions uptake (X kg is the amount of CO_2 in the product, calculated from carbon content). However, because the carbon storage time per definition starts when carbon is sequestered, products with a shorter lifetime also can receive carbon credits. Everything emitted before 100 years is considered as temporary carbon storage and shall be accounted for as emitted now (no discounting of emissions). For intermediate products or cradle-to gate assessments, the lifetime of final product is not known and no carbon credit shall be modeled. However, the biogenic carbon content of the product at factory gate shall be reported.

The sub-category land use and land transformation accounts for uptake and emissions of CO_2, CO and CH_4 due to changes in carbon stock caused by land use and land use change. Carbon exchange for native forest shall be accounted for in this sub-category. Modelling of carbon exchange due to land use and land use change shall follow the guidelines of PAS 2050:2011. The assessment of the impact of land use change shall include all direct land use change occurring within the last 20 years, or the last harvest period, prior to undertaking the assessment (whichever is the longer).

2.6 PEF vs EPD

PEF and PED are similar in the sense that they facilitate analysis of several environmental indicators, while CFP has a narrow focus on climate change impact. The PEF system was developed as a response to the vast amount of EPD-programs, EPD documents and PCRs (Del Borghi et al., 2020), and aim for increased transparency and harmonization across industries. As mentioned in Chapter 2.5, the PEF method is in transition phase, and it is not regulated by any laws. EPDs are also voluntary, but are established as a system for environmental communication and the demand for these have been steadily increasing (Del Borghi et al., 2020), something that also NORSUS has experienced. There are several differences between these, and we will touch upon some of the differences in the following. According to Durão et al. (2020) PEF is a *method* for the calculation of the environmental footprint and EPD is a *communication tool* for LCA study results. However, both EPD and PEF are perceived by European stakeholders as tools for supporting external communication of environmental performance and as basis for public procurement on European level (European Commission, 2017).

One of the major differences between PEF and EPDs is the target audience of the communication. The primary objective of EPDs are business to business communication (B2B), while PEF is also intended for in-house applications and business-to-consumer B2C applications (Durão et al., 2020).

Both EPD and PEF methods shall use the latest characterization factors from IPCC. EN 15804+A2 (CEN, 2019) is an attempt to align the EPD and PEF methods, but they differ in how they treat biogenic carbon. In the guidance document for PEFCR (European Comission, 2018b), it is stated that modeling of biogenic carbon should be done with a simplified manner where only those flows that influence the climate change results are modelled. Because the characterization factors for biogenic CO_2 uptake and emissions are set to zero, only the emissions of biogenic methane (CH_4) should be modelled. According to the EN 15804, biogenic carbon emissions cause the same impact on climate as fossil carbon, but can be neutralized by removing this carbon from the atmosphere. Thus, in the updated EPD methods, removal of biogenic CO_2 is characterized as -1 kg CO_2-eqv./kg biogenic CO_2 and emissions of biogenic CO_2 is characterized as 1 kg CO_2-eqv./kg biogenic CO_2.

Regarding secondary data/background data, data for a PEF study should be PFCR compliant, and a database for PEF-data has been developed. For now, we find that this database lacks transparency and possibilities to adjust the data to fit with the analysis in question.

Application of electricity mix in the production systems are different for EPD and PEF. For modelling of electricity used in the production systems, the Norwegian EPD Foundation states that the national electricity from ecoinvent shall be used in EPDs. According to the PEFCR guidelines, following electricity mix shall be used in hierarchical order, if the set of minimum criteria to ensure contractual instruments are reliable is met:

1. Supplier-specific electricity product;
2. Supplier-specific total electricity mix;
3. 'Country-specific residual grid mix, consumption mix'.

This means that if a guarantee of origin (GO) is purchased, the information from that document shall be used for supplier specific electricity product or -mix when making a PEF. If there is a system for GO but this is not purchased, the 'Country-specific residual grid mix, consumption mix' shall be used. This is calculated for Norway and all countries in Europe and is given in the report European Residual Mixes for 2019 (https://www.aib-net.org/sites/default/files/assets/facts/residual-mix/2019/AIB_2019_Residual_Mix_Results_1_1.pdf). The Country-specific residual grid mix, consumption mix' for Norway is equal to the electricity disclosure for power suppliers given by The Norwegian Water Resources and Energy Directorate (NVE). Per April 2021, the emissions factor for this is 369 g CO_2-eqv/kWh, while the low voltage electricity mix for Norway emissions factor in ecoinvent (used for EPDs) is 23.3 g CO_2-eqv/kWh (ecoinvent 3.6, 2019). The Norwegian electricity mix emissions factor in the EF-database is 461 g CO_2-eqv/kWh.

In the EPD-system, one of the modules are Module D: Benefits and loads beyond the system boundary. In this module reuse and recycling potential, are expressed as net impacts and benefits. In the PEF-system, the Circular Footprint Formula (CFF) has been introduced to share the benefits and burdens of generating and using recycled materials between the two production systems (producer and user of recyclable material). Hence, for reuse and recycling two different principles are chosen:

- EPD: Expansion of the system boundary by inclusion of avoided burdens (module D).
- PEF: Allocation of burdens between product systems producing and using recycled materials.

3 Communication of environmental information

ISO 14026 *Environmental labels and declarations — Principles, requirements and guidelines for communication of footprint information* (ISO, 2017a) provides rules and guidelines for how environmental impacts of a product can be communicated as footprint information. Footprint is defined as metric(s) used to report life cycle assessment results addressing a defined environmental subject that is of interest to society. ISO 14026 does not define the methods or environmental impacts that should be used/addressed. In order to have reliable footprint communication that can be used to compare products, supporting information and footprint communication must be transparent, accurate and relevant.

If the footprint of a product is to be compared with that of another product (the organization's own previous product or another organization's product) the calculation of the footprints must follow the same footprint quantification (i.e. the same footprint program). The analysis of the products must contain all relevant life cycle stages and serve the same function. Even though ISO 14026 allows a comparison with products from other organizations (given certain rules) this might not be accepted in some countries for other reasons not covered by this standard.

ISO 14040 and ISO 14044 also gives a set of rules and regulations regarding comparative assertions that are intended to be disclosed to the public, that is an environmental claim regarding the superiority or equivalence of one product versus a competing product that fulfill the same function. If a comparative assertion is going to be made available to the public, a critical review is required.

A critical review is a process intended to ensure consistency between a life cycle assessment and the principles and requirements given in ISO 14040 and other international standards on LCA. It shall ensure that:

- The methods used to carry out the LCA are consistent with ISO 14040/44 and scientifically and technically valid.
- The data used are appropriate and reasonable in relation to the goal of the study.
- The interpretations reflect the limitations identified and the goal of the study.
- The study report is transparent and consistent.

When defining the scope of the study, it is decided whether a critical review is necessary. At that point it is defined how the critical review shall be conducted and who will conduct the review. A critical review can be conducted either by

1. An expert
   - An internal or external expert independent of the LCA.
   - The review process shall be documented in the LCA report (includes comments of the expert and responses to the recommendations).
2. A panel of interested parties
   - An external independent expert is selected as chairperson for a review panel of at least three members. The members are selected based on qualifications in relation to the goal and scope of the study. These can be other interested parties affected by the conclusion of the study.
   - The review process shall be documented in the LCA report (includes comments of the expert and responses to the recommendations)

4 Substitution

One way of demonstrating an environmental benefit by a certain product, is through the substitution effect. By substituting fossil fuels or other fossil intensive products with wood-based products, one can reduce the amount of fossil GHG emissions. The emissions of biogenic CO_2 can, however, be higher. The main difference between fossil and biogenic CO_2 is timing. The biogenic carbon in wood products is part of the fast carbon cycle that operates in the biosphere (timespan few to thousands of years), while carbon from fossil fuels is part of the slow carbon cycle that move carbon between the atmosphere and the Earth's crust (millions of years). For the indicator *Climate change*, a substitution effect describes the amount of GHG emissions that could be avoided if the fossil-intense product is substituted with a biobased product with the same function. Another term used in the literature on substitution effect is displacement factor (Df) and some relate the substitution factor (SF) to the amount of biogenic carbon in the product. In scientific literature, the substitution effect is calculated on product, organization and market level.

Calculation of the substitution effect is not defined by standards and can be done in different ways, as we have seen in reports that Borregaard has received from other companies and in literature. In Table 4 a few examples on how methods for calculation of the substitution effect are shown. Most of the methods are fitted specifically to the purpose of comparing wood and non-wood products, while the method used by Lyng et al. (2015) can be used for all types of product substitution.

Table 4 Examples of methods for calculation of the substitution effect from some literature sources.

Reference	Method	Comment
Leskinen et al. (2018)	$SF = \frac{GHG_{non-wood} - GHG_{wood}}{WU_{wood} - WU_{non-wood}}$	SF= unitless ratio. $GHG_{non-wood}$= emissions from the use of non-wood alternative expressed in mass units of carbon. GHG_{wood}= emissions from the use of wood alternative expressed in mass units of carbon. WU_{wood}=amounts of wood used in wood alternative expressed in mass units of carbon. $WU_{non-wood}$=amounts of wood used in non-wood alternative expressed in mass units of carbon.
AEG Sundal Collier (2020)	$FSCI_y = VCE_y - \Delta FCS_{(y-1,y)} - PSE_y$	$FSCI_y$ = Forest system climate impact in year y (Mt CO_2e). VCE_y = Total value chain emissions in year y (Mt CO_2e) calculated as Scope 1, 2 and 3 as defined in GRI (2016). $\Delta FCS_{(y-1,y)}$ = Change in forest carbon stock from

		year y-1 to year y (Mt CO_2e). Net growth minus harvest in forest owned by the reporting company. Assume that 1 m3 wood binds 1.3 tonnes of CO_2. PSE_y = Products Substitution Effect in year y (Mt CO_2e). Fossil emissions avoided when forest products are used for solid wood products, pulp and paper, and renewable energy.
AEG Sundal Collier (2020)	$$PSE = \frac{tC_{fossil}}{tC_{forest\ product}}$$	PSE=substitution effect ratio. tC_{fossil}=fossil carbon emissions from substituted product $tC_{forest\ product}$=carbon content in forest product.
Lyng et al. (2015)	$$Net\ GHG = GHG_{wood} - GHG_{non-wood}$$	Net GHG= net effect of substituting non-wood product with wood-product. GHG_{wood}= emissions from production and use of wood product, calculated by use of LCA. $GHG_{non-wood}$= emissions from production and use of non-wood product, calculated by use of LCA. This indicator is used as part of systems expansion methodology; the avoided impacts of the replaced products are credited as negative emissions.

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