Østfoldforskning

Report SUSTAINABLE INNOVATION

Authors: Clara Valente, Ingunn Saur Modahl and Ellen Soldal

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Competitors analysis lignin with addition:

Biogenic CO2 – state-of-the-art in standards and current trends in scientific literature

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Authors: Clara Valente, Ingunn Saur Modahl og Ellen Soldal

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Project Manager

Ellen Soldal

Research Manager

Hanne Lerche Raadal

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Summary

Borregaard would like to increase its internal knowledge on how to handle biogenic CO_2 in future LCA-EPD studies. This state-of-the art study regarding the biogenic carbon and biogenic CO_2 is carried out in parallel with the competitor analysis of lignin against other products. Table 1 and Table 2 present a summary of the revisions of standard, protocols, guidelines and technical reports based on the assessment criteria and on the lignin's applications respectively.

Table 1 Summary of the technical revisions of standard, protocols, guidelines and technical reports based on the assessment criteria (v. 1).

Standards, protocols, guidelines and technical reports	Biogenic carbon definition	Biogenic carbon content	Carbon storage	Biogenic CO_2 emissions & removals	Timing	Characterization factors for biogenic CO_2	Climate change, biogenic CO_2 indicator	LULUC	End of life	Allocation rules	Specifications for product categories (forestry)
NS-EN ISO-14067 (2018)	yes	yes	Yes	shall & should	yes	-1; +1	no	dLUC	yes	not specified	yes
NS-ISO-21930 (2017)	yes	yes	no	shall	no	-1; +1	no	LUC	yes	no	yes
NS-ISO 6707-3 (2018) *	yes	-	-	-	-	-	-	-	-	-	-
NS-EN 16449 (2014)	no	yes	no	no	no	no	no	no	no	not specified	no
NS-EN 16485 (2014)	yes	yes	yes	shall	yes	+1	no	LUC	yes	yes	no
NS-EN 16760 (2015)	no	yes	yes	shall	yes	negative value; zero	no	dLUC & iLUC	yes	yes	yes
EN-15804+A1+prA2 (2017) consolidated document for information CEN/TC 350	no	yes	no	shall	no	0	yes	dLUC & iLUC	no	yes	yes
Product Life cycle Accounting and Reporting standard, GHG protocol (2011)	No (only the term biogenic)	yes	yes	shall	no	+1	no	dLUC & iLUC (optional)	yes	yes	yes
PAS-2050 (2011)	yes	no	yes	shall	yes	No	no	LUC	no	not specified	yes
PEF (2013)	no	no	yes	shall	yes	-1; +1	yes	dLUC & iLUC	no	not specified	no
PEFCR version 6.3 (2017)	no	yes	unclear	shall	yes	unclear	yes	dLUC & iLUC	no	yes	yes
ILCD handbook (2010)	no	no	yes	shall	yes	unclear	unclear	dLUC & iLUC	yes	unclear	yes
CEN/TR-16970 (2016)	no	no	no	unclear	no	-1; +1	no	LUC	yes	unclear	yes

*Note: ISO 6707-3 (2018) regards only terms and definitions.

Table 2 Summary of the technical revisions of standard, protocols, guidelines and technical reports for some application areas for lignin, version 1. Lignin will be defined as a bio based or wood based product based on the context of the study.

Standards, protocols, guidelines and technical reports	Lignin for deep stabilization in roads (road/construction materials)	Lignin in dye-stuffs (textile dye)	Lignin as chelates (agro chemicals)	Lignin as bacterial inhibitor	Lignin in resins (construction materials)	Lignin as dust suppression (road)
NS-EN ISO-14067 (2018)	Only for carbon footprint of product	Only for carbon footprint of product	Only for carbon footprint of product	Only for carbon footprint of product	Only for carbon footprint of product	Only for carbon footprint of product
NS-ISO-21930 (2017)	yes	no	no	no	yes	yes
NS-ISO 6707-3 (2018) [1]	yes	no	no	no	yes	yes
NS-EN 16449 (2014)[2]	might	might	might	might	might	might
NS-EN 16485 (2014)[3]	yes	no	no	no	yes	yes
NS-EN 16760 (2015)	maybe	yes	yes	No	maybe	maybe
EN-15804+A1+prA2 (2017) consolidated document for information CEN/TC 350[4]	might	no	no	no	might	might
GHG protocol (2011) [5]	yes	yes	yes	yes	yes	yes
PAS-2050 (2011) [5]	yes	yes	yes	yes	yes	yes
PEF (2013) [5]	yes	yes	yes	yes	yes	yes
PEFCR version 6.3 (2017)[6]	no	no	no	yes (Feed for food producing animals; pet food)	no	no
ILCD handbook (2010) [5]	yes	yes	yes	yes	yes	yes
CEN/TR-16970 (2016)[7]	might	no	no	no	might	might

[1] NS-ISO 6707-3 -3 (2018) is only about terms and definitions
[2] Calculation of biogenic carbon content for wood and wood-based product
[3] Wood and wood-based products used in construction
[4] Draft amendment EN15084/ FprA2:2019 under consultation, only for information/ not active
[5] As supporting documentations, based on the goal and scope of the study
[6] In accordance to the list of PEFCR from EU: http://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm#final
[7] Complementary document to EN 15084, it is not a stand-alone document

Glossary

Biogenic: produced by living organisms or biological processes, but not fossilized or from fossil sources (WBCSD, 2011); derived from biomass, but not from fossilized or fossil sources (BSI, 2011)

Biogenic carbon: the carbon derived from biomass (NS-EN ISO-14067 , 2018; ISO 6707-3, 2018); carbon derived/contained in biomass (NS-EN 16485, 2014); carbon that is contained in biomass (BSI, 2011).

Biogenic carbon neutrality: balance of biogenic carbon uptake during growth of biomass and release during natural decay or incineration (NS-EN 16485, 2014).

Biomass: material of biological origin, excluding material embedded in geological formations and material transformed in fossilized materials (NS-EN ISO-14067 , 2018); (NS-EN 16485, 2014); (BSI, 2011).

Carbon pools: biomass (above and below ground), dead organic matter (dead wood and litter), and soil organic matter (WBCSD, 2011)

Carbon stock: The total amount of carbon stored on a plot of land at any given time in one or more of the following carbon pools: biomass (above and below ground), dead organic matter (dead wood and litter), and soil organic matter. A change in carbon stock can refer to additional carbon storage within a pool, the removal of CO_2 from the atmosphere, or the emission of CO_2 to the atmosphere (WBCSD, 2011).

Carbon storage: biogenic carbon stored over a specific period of time (NS-EN 16485, 2014); retention of carbon from biogenic or fossil sources or of atmospheric origin in a form other than atmospheric (BSI, 2011).

Characterization factor (CF): factor derived from a characterization model that is applied to convert emissions of substances to the common unit of the impact category indicator (ISO 14040, 2006,). For example, emissions of greenhouse gases are converted to CO_2-equivalents in relation to their potential effect on climate change.

Delayed emissions: emissions that are released over time, e.g. through long use or final disposal phases, versus a single emission at time t (European Commission, 2013).

Direct land use change (dLUC): change in the human use of land within a relevant boundary (NS-EN ISO-14067 , 2018); change in human use or management of land at the location of the production, use or disposal of raw materials, intermediate products and final products or waste in the product system being assessed (NS-EN 16485, 2014).

Forest carbon pools: compartment storing biogenic carbon in the forest: above-ground biomass, below-ground biomass, litter, dead wood and soil organic carbon (NS-EN 16485, 2014).

Fossil carbon: carbon that is contained in fossilized material (NS-EN ISO-14067 , 2018).

Greenhouse gas (GHG): gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared emitted by the Earth's surface, the atmosphere and clouds (NS-EN ISO-14067 , 2018)

GHG removals: absorption and isolation of greenhouse gases from the atmosphere. Removals typically occur when CO_2 is absorbed by biogenic materials during photosynthesis. Removals may also occur when a product absorbs CO_2 during use (BSI, 2011).

Indirect land use change (iLUC): change in the use of land that occurs outside the relevant boundaries. It occurs as a consequence of direct land use change (NS-EN ISO-14067 , 2018); when the demand for a specific land use induces a carbon stock change on other lands (WBCSD, 2011).

Land use (LU): human use or management of land within a relevant boundary. The relevant boundary is the boundary of the system under study (NS-EN ISO-14067 , 2018)

Land use change (LUC): change in the purpose for which land is used by humans (e.g. crop land, grass land, forest land, wetland, industrial land) (BSI, 2011).

Shall, should and may: The terms "shall", "should" and "may" indicate the requirements, the recommendations and options that companies may choose.

- The term "shall" is used to indicate what is required to be in conformance with the standard, guide etc.
- The term "should" is used to indicate a recommendation rather than a requirement.
- The term "may" is used to indicate an option that is permissible.

Temporary carbon storage happens when a product "reduces the GHGs in the atmosphere" or creates "negative emissions", by removing and storing carbon for a limited amount of time (European Commission, 2013).

Time period: period of time when attributable processes take place in a product's life cycle, from when materials are extracted from nature until they are returned to nature at the end-of-life (e.g. incinerated) or leave the studied product's life cycle (e.g. recycled) (WBCSD, 2011).

1 Introduction

Biogenic CO_2 is defined as CO_2 released to the atmosphere due to decay and combustion of biological material. Biomass-based products such as bioenergy have in LCA been considered climate neutral because the amount of CO_2 released can be offset by CO_2 sequestration due to regrowth of biomass. Until few years ago, LCA studies have assumed to do not have a time preference (zero discount rate for emissions) and a common assumption is that the biomass will grow back within the time period of the assessment (usually 100 years) (Cherubini et al., 2012). Hence, many LCA studies overlook the time between emissions and sequestration and assign a global warming potential (GWP) of zero to CO_2 generated by the combustion of biomass (biogenic CO_2). The assumption of carbon neutrality (carbon emissions are equal to carbon uptake) justifies why the emissions of biogenic CO_2 are usually not included in carbon tax and emissions trading schemes (Holtsmark, 2015). Fossil-based systems are assumed to be net contributors of CO_2 emissions, contrary to bio-based systems where CO_2 circulates between the biological system and the anthroposphere, not contributing to increased concentration of CO_2 in the atmosphere.

This concept is more complicated. Both fossil fuels and bio-based systems emit CO_2 during combustion. Due to the assumption of zero climate change potential of biomass combustion, the methods for assessing its global warming impact in environmental analysis tools (e.g. SimaPro) usually do not include the biogenic CO_2 emission (Liu et al., 2017). However, in the last years the climate neutral assumption has been questioned in the scientific community (see e.g.(Breton et al., 2018) for building system; (Liu et al., 2017) for bioenergy system etc.) and standards, guidelines, technical reports have started to describe the concept of biogenic carbon and to introduce indicators to assess the global warming potential of biogenic CO_2 (GWPbio).

1.1 Goal of the study

The goal of this study is to increase the internal knowledge of Borregaard regarding state-of-the-art in reporting of emissions and storage of biogenic CO_2. Ostfold Research will provide relevant literature in a way that can be useful and understandable for Borregaard in future LCA-EPD analyses and in their communication with other stakeholders. The literature search will include standards that have been published and approved, any revisions of these that are in progress, and scientific literature on the subject.

2 Methodology

The literature review has been carried out in this manner:

1) Selecting the International standards (ISO), European standards (EN) and Norwegian standards (NS) reporting the concept of biogenic carbon and biogenic CO_2.
2) Selecting the most appropriate international and European guidelines, protocols and technical reports that include the concept of biogenic carbon and biogenic CO_2.
3) Selecting the most relevant scientific articles published from the year 2015.

The following tools have been used:

1. The terminology database of Standard Norge: https://www.standard.no/en/toppvalg/SNORRE-TERMBASE/, typing the words "biogenic", "carbon"; "biogenic carbon"; "biogenic CO_2";
2. Ostfold Research's database: the LCA standards, guidelines and protocols;
3. Internal seminar at Ostfold Research;
4. EPD Norge: standards and reports used for developing the most recent EPDs for Borregaard;
5. The common research engine of "science direct"; "google scholar" for selecting scientific publications.

2.1 Assessment criteria for standards, protocols, guidelines, handbook and technical reports

- Presence/absence of the biogenic carbon's concept
- Biogenic carbon definition
- Biogenic carbon content
- Carbon storage
- Biogenic CO_2 emissions and removals
- Timing of biogenic CO_2 emissions
- Characterization factors for biogenic CO_2
- Climate change, biogenic CO_2
- Climate change- land use and land use change (LULUC/dLUC/iLUC)
- End-of life stage
- Allocation rule
- Specifications for product categories (forestry)

2.2 Assessment criteria for scientific literature

The most recent articles were selected using the key words and/or "Life Cycle Assessment" (LCA), "biogenic", "biogenic carbon", "biogenic CO_2", "forest", "biomaterial", "forest based products", "lignin", "biochemical", "fiberboard" and "construction materials/works". So far, no results were found typing the words "biogenic carbon/CO_2" & "lignin", "biogenic carbon" & biochemicals". Based on sorting by the year of publication (from 2015) and the remaining words as mentioned above, the publications are shown in the results chapter in Table 6.

3 Results

3.1 Standards, protocols, guidelines and technical reports

Based on the selection described in the methodological chapter of this report, we present only the standards, protocols, guidelines and technical reports which include the concept of biogenic carbon (from a more extensive to a simple citation). The findings are presented in Table 3,

Table 4 and

Table 5. The tables present the name of the document, the geographical coverage, the year of publication, the status, the category of product under assessment and specific comments. As mentioned above, the documents excluding the biogenic carbon concept are not presented in the tables, including ISO 14025:2010 & ISO 14044:2006 applied for developing the most recent EPD for Borregaard (EPD for cellulose, ethanol, lignin and vanillin in the year 2016). A preliminary description of the assessment criteria (see section 2.1) in standards, protocols, guidelines, handbooks and technical reports is presented in chapter 4.

Table 3 ISO, EN and NS standards

Standards	Title	Geographical coverage	Year	Status	Category of products	Note
NS-EN ISO-14067 (2018)	Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification	International	2018	Active	All products	This version cancels and replaces ISO/TS 14067:2013. The requirements for biogenic carbon are revised and clarified.
NS-ISO-21930 (2017)	Sustainability in buildings and civil engineering works - Core rules for environmental product declarations of construction products and services	International	2017	Active	Construction products and services	It provides the principles, specifications and requirements to develop an EPD for construction products and services, construction elements and integrated technical systems used in construction works. It complements ISO 14025
NS-ISO 6707-3 (2018)	Buildings and civil engineering works - Vocabulary - Part 3: Sustainability terms	International	2018	Active	Buildings and civil engineering works	Only terminology
NS-EN 16449 (2014)	Wood and wood-based products - Calculation of the biogenic carbon content of wood and conversion to carbon dioxide	Europe	2014	Active	Wood and wood-based products	It provides a calculation method to quantify the amount of atmospheric carbon dioxide based on the biogenic carbon content of wood.
NS-EN 16485 (2014)	Round and sawn timber - Environmental Product Declarations - Product category rules for wood and wood-based products for use in construction	Europe	2014	Active	Wood and wood-based products in construction	It presents Product Category Rules (PCR) for Type III environmental declarations for wood and wood-based products for use in construction and related construction and in-service processes. It complements the core rules for the product category of construction products as defined in EN 15804 and is intended to be used in conjunction with EN 15804
NS-EN 16760 (2015)	Bio-based products - Life Cycle Assessment	Europe/Norway	2015	Active	Bio-based products	It provides specific LCA requirements and guidance for bio-based products, excluding food,

						feed and energy, based on EN ISO 14040 and EN ISO 14044. It covers bio-based products, derived wholly or partly from biomass.
EN-15804+A1+prA2 (2017) consolidated document for information CEN/TC 350	Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products.	Europe	2017	For information	Construction products	Draft amendment EN15084/ FprA2:2019 under consultation, not yet available to public. It is prepared by Technical Committee CEN/TC 350 and it will supersede EN 15804:2012+A1:2013.

Table 4 Protocols and guidelines

Protocols & guidelines	Title	Geographical coverage	Year	Status	Category of products	Comments
GHG protocol	Product Life Cycle Accounting and Reporting Standard (WBCSD, 2011)	International	2011	Active	All products	Provides requirements and guidance for companies to quantify and report an inventory of GHG emissions and removals (optional) associated with a specific product.
PAS 2050	Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (BSI, Carbon trust and defra, 2011)	International	2011	Active	All products	Give requirements specifically for the assessment of GHG emissions within the life cycle of goods and services, based on the ISO 14040 and ISO 14044.
PEF	Product Environmental Footprint (PEF) Guide (European Commission, 2013)	Europe	2013	Active	All products	EU directive; Recommendation promotes the use of the environmental footprint methods in relevant policies and schemes related to the measurement or communication of the life cycle environmental performance of products or organisations. For further documentations, see also: 1) The technical report entitled " Suggestion for improving Product Environmental Footprint (PEF) Guide" (Zampori and Pant, 2019) and 2) "Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment method" (Fazio et al., 2018).
PEFCR version 6.3	Guidance for the development of Product Environmental Footprint Category Rules (PEFCRs) (European Commission, 2017)	Europe	2017	The content of this PEFCR Guidance is periodically revised by European Commission services.	Categories of products	It provides instructions on how to develop a Product Environmental Footprint Category Rules (PEFCR).

Table 5 Handbook & technical reports

Handbook & technical report	Title	Geographical coverage	Year	Status	Category of products	Comments
ILCD handbook	General guide for Life Cycle Assessment - Detailed guidance (European Commission and Joint Research Centre, 2010)	Europe	2010	Active	All products	General guidance for planning, developing, and reporting both life cycle emission and resource consumption inventory (LCI) data sets.
CEN/TR 16970 Technical report	Sustainability of construction works - Guidance for the implementation of EN 15804 (CEN/TR 16970, 2016)	Europe	2016	Active	Construction products	Complementary document to EN15084, do not replace standards or introduce new rules, no stand-alone document.

3.2 Literature review

Table 6 presents the selection of publications according to the criteria described in the methodological chapter section 2.2. The table presents the authors and year of publication in chronological order, the title of the publication, the geographical context when available, the goal of the study, a short summary and a selection of the main conclusions.

Table 6 Scientific articles

Authors and year	Title	Geographical context	Goal	Summary	Conclusions
(Holtsmark, 2015)	A comparison of the global warming effects of wood fuels and fossil fuels taking albedo into account	Boreal forests (typical Norwegian forest of medium productivity)	To quantify the climate impact of wood fuels and fossil fuels	a) model of the forest stand and model for accumulation of carbon in the atmosphere; b) method for calculating GWPbio including the effect of albedo c) results for GWPbio for the cases with and without collection of residues	The inclusion of albedo effects influences the results of GWPbio that become lower
(Skullestad et al., 2016)	High-Rise Timber Buildings as a Climate Change Mitigation Measure - A Comparative LCA of Structural System Alternatives	Nordic market	To quantify GHG emission reductions by using wood based materials in construction instead of reinforced concrete	Three different approaches for modelling biogenic CO_2: 1. Climate neutral; 2. GWPbio from (Guest et al., 2013)(attributional) 3. GWPbio from Guest et al. (Guest et al., 2013)(consequential modelling)	The use of a GWP bio factor results in a net increase of potential contribution to climate change with approach 2 (from A1-A3) and a net decrease of CC with approach 3 when wood based materials substituted concrete.
(Tellnes et al., 2017)	Comparative assessment for biogenic carbon accounting methods in carbon footprint of products: a review study for construction materials based on forest products	-	To compare different methodologies for biogenic carbon accounting for wood based materials in construction	a) literature review of the main standards and guidelines and b) of the main approaches in literature (from 2010) relevant for biogenic carbon accounting in carbon footprint and EPDs of forest-based construction materials.	Different approaches give different results, no consensus on the methodology to use for calculating biogenic CO_2 in EPD. Differences between standards addressing all products and construction materials.
(Liu et al., 2017)	Analysis of the Global Warming Potential of Biogenic CO_2 Emission in Life Cycle Assessments	-	GWPbio accounting model including long-lived wood products and the decomposition of wood residues. 5 categories of wood based products for energy production are considered	1) forest stand model 2) model for biogenic CO_2 in the atmosphere 3) GWP calculation 4) GWPbio factors at year 0 and at the end of the rotation period	Most of the biogenic CO_2 come from conversion and final use stages. In all the assessed scenarios, the GWPbio is lower than 1 (i.e. advantage for timber products compared to fossil based fuels). Short rotation and fast growing

					biomass have lowest GWPbio value.
(Breton et al., 2018)	Assessing the Climate Change Impacts of Biogenic Carbon in Buildings: A Critical Review of Two Main Dynamic Approaches	-	Comparison of two dynamic LCA models for calculating GWPbio for biomaterials HWP (harvested wood products) in buildings: Dynamic LCA and GWPbio	a) review of the main LCIA approaches for assessing GWP of biogenic carbon b) comparison of two main approaches considering time dimension in LCA (see footnote)	DLCA provides comprehensive framework: to be used in case of better consistency and equal treatment of carbon fluxes; while GWPbio to be used for more complex LCA and in case of time limitation (more simply proxy for users). The authors suggested GWPbio for LCA of buildings.
(Iordan et al., 2018)	Contribution of forest wood products to negative emissions: historical comparative analysis from 1960 to 2015 in Norway, Sweden and Finland	Norway, Sweden, Finland (boreal forests)	Oxidation of HWPs and C uptake by vegetation. Integration of the trends in HWP production in ecoinvent database for CF (carbon footprint) of the forest based products	a) historical data collection (harvested wood per species and per class) b) integration with the emission inventory database c) quantification of the net emission balance between the time of the oxidation of CO_2 (instant emissions) and the net cumulative emissions	The assumption of instantaneous oxidation for harvested material containing carbon at the year of the harvest can bring to large biases. It is recommended to include the negative emissions for HWPs in LCA studies.
(Wang et al., 2018)	Comparison of Product Carbon Footprint Protocols: Case Study on Medium-Density Fiberboard in China	China	Carbon footprint calculation using three different standards/document: PAS2050, GHG protocol and NS-EN ISO-14067	a) state of the art of manufacturing of fiberboard in relation to CF accounting b) comparison of the results for the three protocols considering different requirements including treatment of biogenic carbon	Three standards lead to three different results for CF, also due to different approaches for considering carbon storage. PAS 2050 is highlighted as the preferable protocol for assessing CF of fiberboard and forest products because it includes carbon storage in the calculation as a deduction.

4 Discussion

A brief discussion of the assessment criteria is shown in the sections presenting some examples from the reviewed documents. This part of the report can serve as a starting point for discussion and can preferably be extended later. Not all the standards and protocols are reported here due to limitation in time, and a revision from internal experts would increase the quality further.

4.1 Biogenic carbon definition

There is not a common definition related to the concept of "biogenic carbon". Not all the standards, guidelines and technical reports report this terminology in a clear way. Furthermore, the definition can vary among the international, European and national organizations (see the example here):

- carbon derived from biomass (NS-EN ISO-14067 , 2018);
- carbon derived/contained in biomass (NS-EN 16485, 2014);
- carbon that is contained in biomass (BSI, 2011)

4.2 Biogenic carbon content

NS-EN 16485, 2014 consider the biogenic carbon content as a material inherent property for wood and wood based products. NS-EN 16760 (2015) and NS-EN 16449 (2014) present a method for calculating the biogenic carbon content of wood based products. NS-ISO-21930, 2017 claims that the biogenic carbon content should reflect a physical flow, and an additional indicator should report the removal and emissions associated with C content in bio-based products. EN 15804:2013/prA2:2017 (2017) affirms that the biogenic carbon content should be separately declared for the product and for any accompanying packaging. It should only reflect the amount of carbon contained, or embedded, in that material (BSI, 2011). For intermediate products (from cradle to gate), the biogenic carbon content (physical content and allocated content) shall be reported in the additional technical information (European Commission, 2017).

4.3 Carbon storage

NS-EN ISO-14067 (2018) claims that when biogenic C is stored in products, the C shall be calculated as if it is released or removed at the beginning of the assessed period. For biomass based products, C storage is calculated as removal during the planting growth and as emissions when released at the use or end-of life stages; the biogenic C stored in the bio-based products should also be equal to biogenic C released at the end-of-life (NS-EN 16760 , 2015). The portion of carbon not emitted to the atmosphere during a 100-year period shall be treated as stored carbon (BSI, 2011). Temporary carbon storage shall not be considered in the LCIA results calculation, unless the goal of the study would explicitly aim at including such storage. In this case, the logic behind accounting for biogenic carbon storage is that for the duration of storage e.g. in wood products, the CO_2 is not exerting a radiative forcing as it is temporarily not in the atmosphere (European Commission and Joint Research Centre, 2010). Credits associated with temporary carbon storage or delayed emissions shall not be considered in the calculation of PEF for the default impact categories, unless otherwise specified in a supporting PEFCR (European Commission, 2013).

4.4 Biogenic CO_2 emissions and removals

Biogenic CO_2 emissions and removals shall be included as flows in the LCI and shall/should be documented and reported separately (see table 2, first column).

4.5 Timing of biogenic CO_2 emissions

NS-EN ISO-14067 (2018) reports that the effect of timing of biogenic CO_2 emissions shall be considered "at the beginning of the assessed period", not considering the effect of delayed emissions. NS-EN 16485 (2014) affirms that it may be reported as additional environmental information (on the basis of PAS 2050 or IPPC, KP supplement 2013) and NS-EN 16760, 2015 says that temporal accounting should be taken in account in accordance to the ILCD handbook but reported separately. PAS 2050 (2011) provide a calculation method for delayed emissions from the use and final disposal phases of products as a simplification of the IPCC (2007) approach.

4.6 Characterization factors for biogenic CO_2

NS-EN ISO-14067 (2018) and NS-ISO-21930 (2017) claim that the removal of CO_2 into biomass shall be characterized as -1 kg CO_2e/kg CO_2 of biogenic carbon when the biomass enters the product system in the calculations of the carbon footprint of product (NS-EN ISO-14067) and GWP (NS-ISO-21930); while the emissions of biogenic CO_2 shall be characterized as +1 kg CO_2e/kg CO_2 of biogenic carbon in the calculation of carbon footprint (NS-EN ISO-14067, 2018) and GWP (NS-ISO-21930, 2017). NS-EN 16760 , 2015 says that all biogenic and non-biogenic carbon emissions and removals should be considered using two main approaches: 1) CO_2 sequestrated in biomass during the growing phase is included with negative emissions; while it has a positive value when it is emitted at the end-of -life 2) the CO_2 sequestered during the growing phase has a characterization factor of zero and emission of biogenic CO_2 have a characterization factor of zero. The net result will be equal using the two approaches, but contributions in different steps of the life cycle will be different. The ILCD handbook (2010) claims that both uptake and emissions of biogenic CO_2 have characterization factors in accordance to the IPCC report.

4.7 Climate change, biogenic CO_2

EN-15804+A1+prA2 (2017) includes an impact category named GWP from biogenic carbon emissions and removals having as indicator GWP biogenic and unit kg CO_2 eq. In the PEF (2013) and PEFCR (2017), the impact category climate change includes three sub-categories: climate change-fossil; climate change-biogenic; climate change-land use and land transformation'. When developing the PEFCR, the PEFCR screening study shall always calculate the three sub-categories separately.

4.8 Climate change- land use and land use change (LULUC/dLUC/iLUC)

In many reviewed documents, there is a connection between biogenic CO_2 emissions and removal and ‘land use and land use change’ indicator. NS-EN ISO-14067 (2018) claims that GHG emissions and removals from dLUC within the last decades (usually 20 years’ period as reported in IPCC) shall be assessed in accordance to IPCC guidelines, shall be included in the carbon footprint study and shall be reported separately in the report. Zero emissions for land use is assigned to wood from forest land that still will be forest land. iLUC should be included in the carbon footprint assessment only once international agreed documents will exist. NS-ISO-21930 (2017) affirms that GWP (LUC) shall be declared separately as additional environmental information, including a short interpretation of the data. GHG emissions for LUC will be zero for wood coming from sustainable managed forests. (NS-EN 16485, 2014) follows the IPPC guidelines for national GHG inventory for calculating the GHG emissions derived from LUC due to deforestation. NS-EN 16760 (2015) follows also the requirement from IPCC, where indirect land use only in the interpretation phase, since there is not consensus on the methodology in use. PAS (BSI, 2011) considers the biogenic CO_2 emissions and removals due to carbon stock change from land transformation in the LU categories

4.9 End-of life stage

NS-ISO-21930 (2017) claims that in relation to the end-of-life scenario, the biogenic carbon flow due to emissions (e.g. from combustion) in bio-based materials shall be considered for as emitted biogenic CO_2 in the module when it happens. Bio-based materials that are reused, recycled or combusted at the end-of-life will be zero net contributors to GWP. NS-EN 16485 (2014) considers biogenic carbon as inherent property in the indicators "use in renewable primary energy resources used as raw materials" and "use in not renewable primary energy resources used as raw materials" at the end-of-life. NS-EN 16760 (2015) affirms that the biogenic C stored in the bio-based products should also be equal to biogenic carbon released at the end-of-life for products with complete oxidation.

4.10 Allocation rule

NS-EN 16485 (2014) writes that co-product allocation might be necessary and biogenic carbon is allocated according to physical flows i.e. mass in bio-based products. NS-EN 16760 (2015) affirms that when a physical relationship cannot be established allocation based on biogenic C content should be carried out. PEFCR (2017) indicates that the allocation rules used for all other elementary flows shall also apply to model the biogenic carbon flows.

4.11 Specifications for product categories (forestry)

NS-EN ISO-14067, NS-ISO-21930 (2017), EN 15804+A1+prA2 (2017) and NS-EN 16760 (2015) introduce the concept of wood from sustainable forest management. The basic idea is that sustainable forest management assure that the carbon stock is maintained stable or improved over time. EN 15804:2013/prA2 (2017) assumes that there is no land use or land use change impacts on GWP for bio-based material from sustainably managed forests.

5 Overall conclusion

The state-of-the art on how biogenic carbon is treated in standards highlights that currently there are many approaches present. Even the terms used in the reviewed documents are not consistent with each other. This leads to confusion for the reader. The approaches for calculating the impact of biogenic CO_2 as presented in the reviewed documents will lead to different results in LCA studies, creating uncertainties and unreliability when presenting and explaining the results. Harmonization at least in the terminologies is needed.

The literature review highlights that the scientific community to a larger extent question the assumption of biogenic carbon neutrality in LCA studies (overlook the time between the release and absorption of carbon by forest regrowth through photosynthesis). Researches have revealed that the time gap between the harvest of forest biomass and the regrowth of the forest may influence the climate change contribution of biomass production systems.

Regarding biogenic carbon in bio-products, like lignin-based products, CO_2 is removed and stored in the product over a period of time. Hence, it is important to assess and account biogenic carbon flows (both emissions and removals) in all the stages of the LCA in a transparent way, because if it is done wrong, it can lead to an underestimation or an overestimation of the climate change contribution of the wood-based product. Special consideration should be done for end-of-life calculation of biogenic carbon embedded in products. Because bio-based products have a broad range of applications, the end-of-life options are different. Hence, the emissions during end-of-life should be declared in the end-of-life module, when a modular approach is required.

Another aspect to consider is the time dimension for carbon storage. The assessment time horizon in LCAs are often 100 year for climate change as defined by the IPCC. However, this period might be shorter or longer, depending on the scope of the assessment. As a matter of fact, the role of the temporary carbon storage and delayed emissions for CO_2 is not insignificant. The assumption of instantaneous oxidation of carbon can lead to incorrect calculation and estimation of the benefits for bio-based product from forestry. Despite significant efforts to develop robust methods to account for temporary carbon storage, there is still no consensus on its assessment.

6 Future research

Future research should deal with deepening the technical revisions by trying to solve the unclear points raised during the work and to answer to the potential questions from Borregaard. The goal would be to suggest the most appropriate approach based on the scope of the study for assessing and calculating biogenic CO_2 in future LCA and EPD studies.

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Østfoldforskning
SUSTAINABLE INNOVATION

Gamle Beddingvei 2B
N-1671 Kråkerøy
Telephone: +47 69 35 11 00
Fax: +47 69 34 24 94
firmapost@ostfoldforskning.no
www.ostfoldforskning.no