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Bio-based products - Life cycle assessment - Additional requirements and guidelines for comparing the life cycles of bio-based products with their fossil-based equivalents

Produits biosourcés - Analyse du cycle de vie - Exigences et lignes directrices supplémentaires concernant la comparaison des cycles de vie de produits biosourcés avec leurs équivalents d'origine fossile

Biobasierte Produkte - Ökobilanzen - Zusätzliche Anforderungen und Leitlinien für den Vergleich der Lebenszyklen von biobasierten Produkten mit ihren fossilen Pendants

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Introduction

Bio-based products from forestry and agriculture have a long history of application, such as paper, board and various chemicals and materials. The last decades have seen the emergence of new bio-based products in the market. Some of the reasons for the increased interest lie in the benefits of bio-based products in relation to the depletion of fossil resources and climate change. Bio-based products can also provide additional product functionalities. These developments have triggered a wave of innovation with the development of knowledge and technologies allowing new transformation processes and product development.

Acknowledgingtheneedforcommonstandardsforbio-basedproducts,theEuropeanCommissionissued mandate M/492[1], resulting in a series of standards developed by CEN/TC 411 during 2012-2017, with a focus on bio-based products other than food, feed and biomass for energy applications. This document was developed after the expiration of the mandate, upon the initiative of CEN/TC 411/WG 4.

The standards of CEN/TC 411 "Bio-based products" provide a common basis on the following aspects:

— common terminology;

— bio-based content determination;

— life cycle assessment (LCA);

— sustainability aspects; and

— declaration tools.

It is important to understand what the term bio-based product covers and how it is being used. The term 'bio-based' means 'derived from biomass'. Bio-based products (bottles, insulation materials, wood and wood products, paper, solvents, chemical intermediates, composite materials, etc.) are products which are whollyor partlyderived from biomass. Itis essential to characterize the amount of biomass contained in the product by, for instance, its bio-based content or bio-based carbon content.

The bio-based content of a product does not provide information on its environmental impact or sustainability, whichcanbe assessed through LCAand sustainabilitycriteria. Inaddition, transparent and unambiguous communicationwithinbio-based value chains is facilitated bya harmonized framework for certification and declaration.

This document has been developed with the aim to set a framework for fair comparisons between fossil-based and bio-based product systems through LCA. Today, some comparisons have been made in a way which (consciously or unconsciously) disadvantages the bio-based product systems related to a number of aspects. Often, this is due to an incorrect application of LCA, and not being in full conformance with the international LCA standard EN ISO 14044. In this document some of these issues are addressed when setting the framework for how a correct study is to be performed.

The general methodology to perform LCAs of products is described in the standard mentioned above as well as in EN ISO 14040, EN ISO 14067 and, more specific for bio-based products, in EN 16760 and EN ISO 22526-1 to EN ISO 22526-3 and ISO 22526-4. However, significant problems often arise when it comes to making well-balanced comparative LCAs between bio-based and fossil-based product systems. This document provides additional requirements and guidelines to enable practitioners to perform comparative LCA studies involving bio-based products with equivalent fossil-based products and to disclose the results. Fossil resource use increases the total amount of carbon in the biosphere while bio-

[1] A mandate is a standardization task embedded in European trade laws. Mandate M/492 was addressed to the European Standardization bodies, CEN, CENELEC and ETSI, for the development of horizontal European Standards for bio-based products.

based systems can operate in a renewable way within this system (where harvesting and growth rates are in balance). When biomass grows, the plant captures carbon dioxide (CO_2) from air or water. This CO_2 can either be stored as products or in soil, or released when the biomass decays or burns (at the end of life).

This document sets requirements for comparisons between fossil-based and bio-based product systems. There can in some cases be many other options (which can be better than both the fossil-based and bio-based option), but this is outside of the scope of this document.

1 Scope

This document provides requirements and guidelines for comparing the life cycles of bio-based products with their fossil-based equivalents.

NOTE The term "equivalents" generally refers to the "functional equivalence".

This document builds on existing LCA methodology and provides requirements and guidance on specific topics relevant for making well-balanced comparisons.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN ISO 14025:2010, *Environmental labels and declarations — Type III environmental declarations — Principles and procedures (ISO 14025:2006)*

EN ISO 14040:2006,[2] *Environmental management — Life cycle assessment — Principles and framework (ISO 14040:2006)*

EN ISO 14044:2006,[3] *Environmental management —Life cycle assessment — Requirements and guidelines (ISO 14044:2006)*

EN ISO 14067:2018, *Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification (ISO 14067:2018)*

EN 16575:2014, *Bio-based products — Vocabulary*

EN 16760:2015, *Bio-based products — Life Cycle Assessment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 14040:2006, EN ISO 14044:2006, EN 16575:2014 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp/

— IEC Electropedia: available at https://www.electropedia.org/

3.1
carbon footprint of a product
CFP
sum of *GHG emissions* (3.5) and *GHG removals* (3.6) in a product system, expressed as CO_2 equivalents and based on a life cycle assessment using the single impact category of climate change

Note 1 to entry: A CFP can be disaggregated into a set of figures identifying specific GHG emissions and removals. A CFP can also be disaggregated into the stages of the life cycle.

[SOURCE: EN ISO 14067:2018, 3.1.1.1]

[2] As impacted by EN ISO 14040:2006/A1:2020.
[3] As impacted by EN ISO 14044:2006/A1:2018 and EN ISO 14044:2006/A2:2020.

3.2
carbon dioxide equivalent
CO_2 equivalent
CO_2e
unit for comparing the radiative forcing of a GHG (3.3) to that of carbon dioxide

Note 1 to entry: Mass of a GHG is converted into CO_2 equivalents by multiplying the mass of the GHG by the corresponding GWP (34) or GTP of that gas.

Note 2 to entry: In the case of GTP, CO_2 equivalent is the unit for comparing the change in global mean surface temperature caused by a GHG to the temperature change caused by CO_2.

[SOURCE: EN ISO 14067:2018, 3.1.2.2]

3.3
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 radiation emitted by the Earth's surface, the atmosphere and clouds

Note 1 to entry: For a list of GHGs, see the latest IPCC Assessment Report.

[SOURCE: EN ISO 14067:2018, 3.1.2.1]

3.4
global warming potential
GWP
index, based on radiative properties of *GHGs* (3.3), measuring the radiative forcing following a pulse emission of a unit mass of a given GHG in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide (CO_2)

Note 1 to entry: "Index" as used in this document is a "characterization factor" as defined in ISO 14040:2006, 3.37.

Note 2 to entry: A "pulse emission" is an emission at one point in time.

[SOURCE: EN ISO 14067:2018, 3.1.2.4]

3.5
greenhouse gas emission
GHG emission
release of a *GHG* (3.3) into the atmosphere

[SOURCE: EN ISO 14067:2018, 3.1.2.5]

3.6
greenhouse gas removal
GHG removal
withdrawal of a *GHG* (3.3) from the atmosphere

[SOURCE: EN ISO 14067:2018, 3.1.2.6]

3.7
greenhouse gas emission factor
GHG emission factor
coefficient relating activity data with the *GHG emission* (3.5)

[SOURCE: EN ISO 14067:2018, 3.1.2.7]

3.8
organization
person or group of people that has its own functions with responsibilities, authorities and relationships to achieve its objectives

Note 1 to entry: The concept of organization includes, but is not limited to, sole-trader, company, corporation, firm, enterprise, authority, partnership, charity or institution, or part or combination thereof, whether incorporated or not, public or private.

[SOURCE: EN ISO 14067:2018, 3.1.5.1]

3.9
supply chain
those involved, through upstream and downstream linkages, in processes and activities relating to the provision of products to the user

Note 1 to entry: In practice, the expression "interlinked chain" applies from suppliers to those involved in end-of-life processing, which may include vendors, manufacturing facilities, logistics providers, internal distribution centres, distributors, wholesalers and other entities that lead to the end user.

[SOURCE: EN ISO 14067:2018, 3.1.5.2]

3.10
primary data
quantified value of a process or an activity obtained from a direct measurement or a calculation based on direct measurements

Note 1 to entry: Primary data need not necessarilyoriginate fromthe productsystemunder study because primary data might relate to a different but comparable product system to that being studied.

Note 2 to entry: Primary data can include GHG emission factors (3.7) and/or GHG activity data (defined in ISO 14064-1:2006, 2.11).

[SOURCE: EN ISO 14067:2018, 3.1.6.1]

3.11
site-specific data
primary data (3.10) obtained within the product system

Note 1 to entry: All site-specific data are primary data but not all primary data are site-specific data because they may be obtained from a different product system.

Note 2 to entry: Site-specific data include *GHG emissions* (3.5) from GHG sources as well as *GHG removals* (3.6) by GHG sinks for one specific unit process within a site.

[SOURCE: EN ISO 14067:2018, 3.1.6.2]

3.12
secondary data
data which do not fulfil the requirements for *primary data* (3.10)

Note 1 to entry: Secondary data can include data from databases and published literature, default emission factors from national inventories, calculated data, estimates or other representative data, validated by competent authorities.

Note 2 to entry: Secondary data can include data obtained from proxy processes or estimates.

[SOURCE: EN ISO 14067:2018, 3.1.6.3]

3.13
uncertainty
parameter associated with the result of quantification that characterizes the dispersion of the values that could be reasonably attributed to the quantified amount

Note 1 to entry: Uncertainty can include, for example:

— parameter uncertainty, e.g. *GHG emission factors* (3.7), activity data;

— scenario uncertainty, e.g. use stage scenario, end-of-life stage scenario;

— model uncertainty.

Note 2 to entry: Uncertainty information typically specifies quantitative estimates of the likely dispersion of values and a qualitative description of the likely causes of the dispersion.

[SOURCE: EN ISO 14067:2018, 3.1.6.4]

3.14
fossil carbon
carbon that is contained in fossilized material

Note 1 to entry: Examples of fossilized material are coal, oil and natural gas and peat.

[SOURCE: EN ISO 14067:2018, 3.1.7.3]

3.15
land use
LU
human use or management of land within the relevant boundary

Note 1 to entry: In this document, the relevant boundary is the boundary of the system under study.

Note 2 to entry: Land use is often referred to as "land occupation" in life cycle assessment (LCA).

[SOURCE: EN ISO 14067:2018, 3.1.7.4]

3.16
direct land use change
dLUC
change in the human use of land within the relevant boundary

Note 1 to entry: In this document, the relevant boundary is the boundary of the system under study.

Note 2 to entry: Land use change happens when there is a change in the land-use category as defined by the IPCC (e.g. from forest land to cropland).

[SOURCE: EN ISO 14067:2018, 3.1.7.5]

3.17
indirect land use change
iLUC
change in the use of land which is a consequence of *direct land use change* (3.16), but which occurs outside the relevant boundary

Note 1 to entry: In this document, the relevant boundary is the boundary of the system under study.

Note 2 to entry: Land use change happens when there is a change in the "land-use category" as defined by the IPCC (e.g. from forest land to cropland).

EXAMPLE If land use on a particular parcel of land changes from food production to biofuel production, land use change might occur elsewhere to meet the demand for food. This land use change elsewhere is indirect land use change.

[SOURCE: EN ISO 14067:2018, 3.1.7.6]

4 Abbreviations

BPP	Biotic production potential
C	Carbon
CF	Characterization factor
CFP	Carbon footprint of products
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
dLUC	Direct land use change
EOL	End-of-life
EPD	Environmental product declaration
EU	European Union
GHG	Greenhouse gas
GWP	Global warming potential
HANPP	Human appropriation of net primary production
iLUC	Indirect land use change
IPCC	The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment

LU	Land use
LUC	Land use change
LULUC	Land use and land use change
m^2	Square meter
$m^2 \times a$	Square meter times year
m^2a	Square meter per annum (i.e. year)
MP	Microplastics
MPEP	Microplastic emission potential
N_2O	Nitrous oxide
NPP	Net primary production
PCR	Product category rules
PDF	Potentially disappeared fraction (of species)
PE	Polyethylene
PEF	Product environmental footprint
PEFCR	Product environmental footprint category rules
PET	Polyethylene terephthalate
PLA	Polylactide, polylactic acid
PP	Polypropylene
PS	Polystyrene
RMPEP	Relative index MPEP
SOC	Soil organic carbon
SOC_0	Soil organic carbon at time zero
$SOC_{(0-T)}$	Soil organic carbon at time zero minus T
SOM	Soil organic matter
US	United States
WWTP	Wastewater treatment plant

5 General principles for LCA studies which compare bio-based with fossil-based products

5.1 General

The principles from EN ISO 14040:2006, 4.1 apply for this document. They are followed in both planning, conducting, and reviewing anLCAstudy.These principles are furtherelaborated in5.2-5.8 below to cover the comparison of bio-based products with their fossil-based equivalents.

5.2 Life cycle perspective

There are many possible differences between the product systems of bio-based products and their fossil-based equivalents, the most prominent being in the supply chain and at end-of life. Therefore, comparisons are only possible using a life-cycle perspective.

Due to different supply chains (e.g. agriculture and forestry vs. mining and extraction), data availability, quality and appropriateness can deviate considerably between the systems under study.

Also, end-of-life for products can differ considerably due to the specific properties (such as recyclability) and the availability of different treatment options.

Bio-based and fossil-based carbon flows are treated consistently in comparative studies that handle both flows, or in comparisons of studies that handle one or the other of the two flows, taking into account the different attributes between these flows.

5.3 Environmental focus

LCAfocuses onaddressing environmental aspects and impacts for distinctivelydifferent productsystems related to the safeguards natural resources, human health, and ecosystems. Due to the different nature of the supply chains also different economic and social impacts can be observed, see 7.4.1.1. These impacts are typically out of scope but can be addressed in broader assessments.

5.4 Relative approach (and functional unit)

Functional equivalence is crucial for meaningful comparisons and corresponding interpretations. An absolute functional equivalence can be demonstrated for products during their use phase.

5.5 Iterative approach

Iterations between LCA phases help to support proper interpretation when making comparisons.

5.6 Transparency

Transparency is a key principle for LCA studies comparing bio-based and fossil-based product systems, as for all LCA studies. In particular, this is relevant where conventions (e.g. carbon modelling) and value choices are applied. Transparency along all four phases of an LCA study (goal and scope, inventory, impact assessment and interpretation) helps to ensure proper interpretation (8.3) and appropriate reporting (8.4), including the enabling of a critical review (8.5).

5.7 Comprehensiveness

The consideration of all aspects of the natural environment, human health, and resources in LCA avoids burden shifting and identifies trade-offs.

For bio-based and fossil-based product systems this includes impacts of both systems, understanding the different impact pathways in an overall perspective.

Impacts can be driven by emissions (e.g. contribution to global warming or eutrophication) which are harmful for the natural environment or can be related to other inventory data like resource depletion, land occupation or land transformation (7.4.1.2).

5.8 Priority of scientific approach

Decisions for comparing bio-based with fossil-based product systems are preferably based on natural science, in particular for modelling decisions related to carbon flows, carbon content, carbon storage and emissions and removals. If conventions or value choices are used to determine the difference between two product systems, they are transparently documented and investigated during interpretation.

6 General requirements for LCA studies which compare bio-based with fossil-based products

When performing LCA according to this document, the requirements in EN ISO 14040, EN ISO 14044, EN ISO 14067 and EN 16760 shall be met.

The comparison of bio-based and fossil-based products relates to many challenges as there are inherent differences betweenthe systems and a balanced modelling is difficult to achieve. To support a meaningful interpretation and appropriate reporting, data collection and documentation shall be guided by the principles for LCA in general and the specific aspects of comparing bio-based with fossil-based in particular, where e.g. the feedstock or raw material (such as oil, wood or crops) sourcing can be the dominating or discriminating stage of the life cycle.

Due to different supply chains data availability, quality and appropriateness can deviate considerably between bio-based and fossil-based raw material and the same can be valid for different end-of-life options. In addition, temporal boundaries can deviate.

This asymmetry between the systems shall be considered through a careful set up of any LCA study that intends to compare the product systems and shall be considered also when comparing the outcome of different studies of bio-based and fossil-based systems. Differences can be compared given that the modelling follows the same principles and assumptions, and the context of each study are equivalent.

LCAoffersavarietyoftechniquestolimitbiasintroducedbysuchasymmetriesandensurecomparability. Main techniques are:

— sensitivity analysis for any modelling assumption based on value choices or conventions; and

— statistical procedures to explore the relevance of data gaps.

Given that asymmetries cannot be avoided, the transparent documentation of limitations related to goal and scope of the study and further reporting requirements of value choices, rationales, and expert judgements, followed up with a comprehensive critical review, are pre-requisites for meaningful conclusions to be drawn.

EN ISO 14044:2006 sets requirements for comparative studies, which shall be the basis when making comparisons between bio-based and fossil-based product systems, see text box below.

EN ISO 14044:2006, 4.2.3.7 Comparisons between systems

In a comparative study, the equivalence of the systems being compared shall be evaluated before interpreting the results. Consequently, the scope of the study shall be defined in such a way that the systems can be compared. Systems shall be compared using the same functional unit and equivalent methodological considerations, such as performance, system boundary, data quality, allocation procedures, decision rules on evaluating inputs, and outputs and impact assessment. Any differences between systems regarding these parameters shall be identified and reported. If the study is intended to be used for a comparative assertion intended to be disclosed to the public, interested parties shall conduct this evaluation as a critical review.

Furthermore, the requirements for comparability set in the bullet list of EN ISO 14025:2010, 6.7.2 shall be met, see below for the list (adapted to the scope of this document):

a) The products compared have at least one identical function.

b) The goal and scope definition for the LCA of the product, according to ISO 14040, has the following characteristics:

   — the functional unit is identical and expressed in the same measurement system;

   — the system boundary is equivalent;

   — the description of data is equivalent;

   — the criteria for the inclusion of inputs and outputs are identical; and

— the data quality requirements including coverage, precision, completeness, representativeness, consistency, reproducibility, sources and uncertainty are equivalent.

c) For the inventory analysis:

— the methods of data collection are equivalent;

— the calculation procedures are identical; and

— the allocation of material and energy flows and releases is equivalent.

d) Impact category selection and impact assessment method, if applied, are identical. The relevant impact categories should be assessed, with any exclusions justified.

NOTE: The selection of impact categories is part of the iterative nature of an LCA,

e) Predetermined parameters for reporting of LCA data (inventory data categories and impact category indicators) are identical.

f) Requirements for provision of additional environmental information, including any methodological requirements (e.g. specifications for hazard and risk assessment) are equivalent.

g) Materials and substances to be declared (e.g. information about product content, including specification of materials and substances that can adversely affect human health and/or the environment, in all stages of the life cycle) are equivalent.

In order to compare bio-based and fossil-based product systems based on information modules, either the environmental impacts of omitted life cycle stages of the products shall not be significant, or the data of omitted life cycle stages shall be identical within the accepted uncertainty of the data. In this context, determination of significance shall take account EN ISO 14044:2006, 4.2.3.3.3.

7 Guidance and requirements for goal and scope, inventory and impact assessment

7.1 General

For comparing bio-based with fossil-based product systems all aspects in Clause 7 for both systems shall becomprehensivelyaddressed.Annex Acontainsexamplesandfurtherguidancerelatedtotheseaspects.

7.2 Guidance and requirements on biogenic and fossil carbon flows

7.2.1 Modelling considerations for carbon flows

7.2.1.1 General

There are different ways to handle carbon containing elementary flows in a life cycle inventory, different approaches to handle allocation of carbon flows for a process or processes shared by more than one product system, including those at end-of-life; and different approaches to treatment of fossil and biogenic carbon flows in life cycle impact assessment.

The main issues arising for fossil and biogenic carbon flows respectively are:

— Different methodological approaches can reveal or obscure that fossil carbon, once extracted from the ground, can ultimately be released as a CO_2 emission to the atmosphere. If a methodological approach obscures the CO_2 emission, it shall be described.

— Some methodological approaches do not take into account that biogenic CO_2 has beenremoved from the atmosphere nor take into account any benefit where such CO_2 is not subsequently emitted.

— Theimpact assessment for carbonflows, removal, and emissions,canbe seenwith two different time perspectives: long term or short term. With long-term perspective all removals and emissions are accounted for as occurring now, with short term perspective removals and emissions accounted for up to a specified time horizon. The choice of time perspective is inherently a value judgment which will impact the end result.

— Theuse of onlytheshort-term perspectivecanobscure the fact that fossilcarbononceextracted from the ground can ultimately be released as a CO_2 emission to the atmosphere. On the other hand, the use of only the long-term perspective does not allow sufficient differentiation between the CO_2 emissions from incineration and landfilling since the immediate emissions of incineration and the future emissions from landfill are treated equally.

NOTE 1 Non-CO_2emissionsare capturedusing the short-termperspective but the long termCO_2emissionsfrom landfill would not be sufficiently differentiated from the immediate CO_2 emissions from incineration.

The complete picture is only obtained with the use of both perspectives but is not common practice.

Comparative studies should present both time perspectives but as a minimum, in a comparison between bio-based and fossil materials, the selected approach shall be stated and justified in the goal and scope. Any interpretation of the results shall be restricted to that specific scope. It shall also be consistently applied to both product systems.

NOTE 2 Most often 100 years is used as the time horizon for short-term perspective.

NOTE 3 Guidance on how to handle algae grown with fossil CO_2 can be found in A.1.1.

7.2.1.2 Life cycle inventory (LCI)

Greenhouse gas (GHG) emissions and removals arising from fossil carbon sources and biogenic carbon sources and sinks shall be included and listed separately in the inventory.

The GHG inventory shall cover all carbon flows in such a way that the effect of choices related to stored or released carbon (biogenic or fossil, respectively) and storage period(s) at the product end-of-life can be assessed in sensitivity analyses during the interpretation phase (see 8.3). The biogenic and fossil carbon can also flow into other products by mechanical, chemical, or organic recycling.

Multi-functionalityshall be handled, if possible, bysubdivisionor bysystem expansionto avoid allocation (following EN ISO 14044).

Where allocation cannot be avoided it is important to realize that allocation can introduce problems for the accounting of biogenic carbon flows. Using different approaches for handling of biogenic carbon in allocation situations can lead to different results and conclusions and the selected approach for that allocation shall be stated and justified in the goal and scope.

Biogenic and fossil carbon content and flows shall be allocated reflecting the physical flows according to stoichiometric rules irrespective of the allocation chosen for the process. Alternative allocation approaches can lead to the modelled biogenic and fossil carbon flows not reflecting the actual physical content and flows.

NOTE EN 16485:2014 contains examples on how to allocate biogenic carbon.

For cradle to gate studies, biogenic or fossil carbon content in the products shall be reported separately to allow to calculate carbon emissions in end-of-life.

The ideal comparison should be made for cradle to grave. If relative comparisons (difference expressed in %) are to be done cradle to gate, then the downstream stages of the product systems should be modelled, and all assumptions related should be clearly documented and should be adapted for both product systems.

7.2.1.3 Impact assessment

To carry out life cycle impact assessments, all biogenic and fossil carbon emissions and removals should be considered. The impacts shall be reported separately, e.g. climate change – biogenic, climate change – fossil. Two examples can be found in A.1.2.

The short-term perspective, which captures the rate of change, should use GWP100 as the metric and the long-term perspective, which accounts for the final equilibrium temperature, should use GTP100 as the metric.

7.2.2 Quantification of biogenic GHG removals and emissions

7.2.2.1 General

There are different ways to deal with biogenic carbon removals and emissions in LCA. Annex B provides an overview of the different approaches used in LCA standards.

The main issues that can be observed are:

— There is a need for a harmonized and transparent approach on how the biogenic carbon removals andemissionsaretobehandledincludingtimeperspectivesinimpactassessment.Theinconsistency in approaches of handling the removals and emissions of biogenic CO_2, in the life cycle inventory and when performing impact assessments results in different outcomes and interpretations.

— There are different approaches regarding how to report biogenic carbon removals and emissions in cradletogatestudiese.g.whetherbiogeniccarbonremovalsaretobeincludedasanegativeemission when the positive emissions from the end-of-life is not included in the scope.

7.2.2.2 Life cycle inventory

Biogenic carbon is captured as CO_2 from the atmosphere and sequestered during biomass growth, a process commonly referred to as photosynthesis. This biogenic carbon can at the end of the life cycle be emitted as CO_2, CO or CH_4 as a result of the oxidation and/or reduction of biogenic carbon in the product by means of its transformation or degradation (e.g. incineration, biodegradation, landfilling). The inventory of biogenic carbon flows shall include both the removals and the emissions with dedicated elementary flows e.g. carbon dioxide (biogenic). Biogenic carbon emissions and removals shall be included and shall each be reported separately in both cradle to gate and cradle to grave assessments.

For cradle to gate studies, biogenic carbon content in the products shall be reported separately to allow calculation of biogenic carbon emissions in end of life.

7.2.2.3 Impact assessment

As described in EN 16760:2015, one of the below two approaches may be applied for modelling CO_2 emissions and removals related to biomass:

a) The CO_2 incorporated in biomass during the growth phase is inventoried as a removal during the cultivation/growth phase, and as an emission when it is released at end-of-life or throughout the life cycle. The CO_2 removal shall thenbe characterized inthe LCIAas −1, while emissions of biogenic CO_2 correspondingly shall be characterized in the LCIA as +1 (referred to as the −1/+1 approach). Or,

b) The CO_2 incorporated in biomass during the growth phase and the corresponding emissions throughout the entire lifecycleare bothcharacterized with acharacterizationfactorofzero(referred to as the 0/0 approach).

NOTE 1 Characterization factors are used to quantify the potential impact of the modelled CO_2 emissions and uptakes (within the climate change impact category).

Other biogenic GHG emissions (e.g. CH_4) should always be characterized as they often have a higher radiative forcing than CO_2.

For bio-based products, the biogenic carbon shall be quantified applying the −1/+1 approach. For these products, there are different end-of-life options. This includes incineration, mechanical and chemical recycling, industrial composting, *in situ* biodegradation, and landfilling. The 0/0 approach shall only be used when the biogenic carbon taken up is totally oxidized and released as CO_2. This can be the case for energetic use of biomass.

A simplified approach for −1/+1 is to consider for the removal (−1) the biogenic CO_2 embedded in the bio-based product by using stoichiometry or the biogenic carbon content. This approach may be used if there is a lack of completeness and accuracy of the biogenic carbon emissions during the production of the bio-based product.

NOTE 2 EN 16485:2014 contains examples on how to calculate embedded CO_2.

7.2.3 Biogenic carbon storage in products

7.2.3.1 General

Biogenic carbon storage is the sequestration of carbon in products for a certain period resulting in a temporary reduction of the CO_2 concentration in the atmosphere, see E.3 in EN ISO 14067:2018 for further guidance. If biomass is harvested and biogenic carbon is stored in bio-based products, emissions can be temporarily delayed or avoided long-term. This can lead to a temporary or long-term reduction of CO_2 in the atmosphere, and, therefore, not increase global warming. A distinction is made between carbon that is released within a short-term (temporary storage) and long-term (beyond a longer and specified time-horizon, and which is then considered as "permanent" storage). If the effect of timing of biogenic removals and emissions are considered, the temporal horizon should be consistent with the storage period.

The main issues are:

— According to the standards and guidelines reviewed in Annex B, delayed emissions due to temporary carbon storage are not included in the final footprint result but some allow them to be provided as additional information. By using this approach, an advantage of some bio-based products, i.e. the possible delay in emissions can be missed. Yet, there is increased interest in standardization and in policy to incorporate this consideration of time and the potential of bio-based products to provide temporary or permanent carbon storage.

EXAMPLE One such effort is the carbon removal certification within the EU [17].

— There is no harmonized methodological approach in calculating the benefit of delayed emissions. There are different approaches presented and further guidance and consensus are needed for the appropriate method for assessment.

— The benefit from delayed emissions depends on the chosen time horizon. Most often 100 years is used as the time horizon, this is a value choice and not based ona scientific definition. Most standardsdo not report anyspecifictime horizonafter whichcarbonremoved from theatmosphere (e.g. during

biomassgrowth)isconsideredasnolongerreleased,andhenceaspermanentlystored.Valuechoices also apply to the definition of a minimum time, if any, to factor in the benefits of a temporary carbon storage (e.g. minimum 10 years or 20 years or 50 years of storage in the product, before being released back to the atmosphere).

— The lifetime of many products is much shorter than 100 years. For many packaging products the lifetime is short and the possibility of the recycling of these products in new products and storing carbon for longer duration is not considered, although the same carbon sequestered can stay in the economy for a longer time period. If carbon can remain in the loop by stimulating recycling of bio-based products, this is advantageous.

7.2.3.2 Goal and scope

It shall be assessed whether accounting of time is relevant or not for the product in scope.

The choice of time period should be transparently reported and justified, based on scientific evidence to the extent possible, and sector guidance or product category rules can be a source of this information when available.

7.2.3.3 Life cycle inventory

For a cradle to grave study, an inventory shall be made considering the temporal profile of the emissions and the possible period of storage of carbon in the product before reaching end-of-life stage, following what is stated in the goal and scope.

7.2.3.4 Impact assessment

7.2.3.4.1Accounting for temporary storage

To better capture the impact of time, dynamic approaches have been developed which consider use of time dependent characterization factors for the calculation of GWP. Dynamic LCA approach may be followed for such more accurate estimation of the impact of delayed emissions.

If the accounting of delayed emissions is declared as relevant in the objectives of the study, it should be taken into account but reported separately. See 6.4.8 EN ISO 14067:2018 for assessing the effect of the timing. For the assessment of effects due to temporary biogenic carbon storage, the method proposed in the ILCD Handbook [14] may be followed. This is based on linear discounting of emissions over a 100-year time period. An example on how this can be calculated can be found in A.2.

7.2.3.4.2Accounting for permanent carbon storage

The portion of the stored carbon not emitted to the atmosphere within the chosen time period may be treated as “permanently” stored. Carbon storage below the chosen time period shall not be counted as permanent storage.

7.3 Guidance and requirements for establishing systems for a comparison based on functional relevance

7.3.1 Data requirements and sources / Data asymmetry

7.3.1.1 General

Dataqualityhasanimportantinfluenceontheoutcomeoftheh LCAstudyandshallbeconsistentlyhandled and transparently reported for studies comparing bio-based and fossil-based products.

Data quality should be equivalent as far as possible between compared product systems. If this is not possible, a sensitivity analysis should be performed, and a conservative approach should be followed. When there are differences in data quality between the compared bio-based and fossil-based product

systems, these shall be addressed and justified in the LCA report and limitations related to the data quality shall be reported.

In case of significant differences in data quality between the systems, the peer review team shall make a statement thereof in the review report.

7.3.1.2 Goal and scope

7.3.1.2.1General

The selection of data should be consistent with the goal and intended use of the LCA study results and be justified in view of the availability and quality of data. Within the scope phase the data and data quality requirements shall be consistently defined for the two systems, in particular related to environmental aspects that are unique to the two systems.

This can be relevant for temporal considerations related to the reversibility of environmental impacts (e.g. land use), to specifics regarding emissions to the environment (e.g. toxicity, persistence), the treatment of geographically explicit data and the treatment of data gaps and assumptions.

The definition of the goal and scope of a study provides the initial plan for conducting the life cycle inventory phase of an LCA, where data are collected and validated.

7.3.1.2.2Data quality requirements

The following data quality requirements for an LCA study shall be established during goal and scope phase and transparently reported with the LCA study:

a) time-related coverage: age of data and time period;

b) geographical coverage: geographical area from which data for unit processes was used for the assessment;

c) technology coverage: specific technology or technology mix;

d) precision: measure of the variability of each data value expressed (e.g. variance);

e) completeness: percentage of total flow that is measured or estimated;

f) representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e. geographical coverage, time period and technology coverage);

g) consistency: qualitative assessment of whether or not the study methodology is applied uniformly to the various components of the sensitivity analysis;

h) reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the assessment;

i) sources of the data; and

j) uncertainty of the information.

NOTE The list above is adapted from EN ISO 14044:2006, 4.2.3.6.2.

A two-step approach shall be taken for the data quality evaluation:

— the data quality requirements according to items a) to e) above shall be characterized for the assessment; and

— data shall be assessed and validated with respect to the requirements for items a) to j) above.

7.3.1.2.3Geographical and technology coverage of data

As a rule, site specific data for production of products shall be used as a basis for calculations.

Site-specific data shall be collected for individual industrial processes where the organization undertaking the studyhasfinancial or operational control. The data shall be representative of the process for which they are collected. Site-specific data should preferably be used for those unit processes that are most important and not under financial or operational control.

NOTE 1 The most important processes are those which together contribute at least 80 % to any of the impact categories, starting from the largest to the smallest contributions after cut-off (see EN ISO 14044:2006, 4.2.3.3.3).

NOTE 2 Site-specific data refer to either direct emissions (determined through direct monitoring, stoichiometry, mass balance or similar methods), activity data (inputs and outputs of processes that result in emissions or removals) or emission factors. Site-specific data can be collected from a specific site or can be averaged across all sites that contain the process within the system under study. They can be measured or modelled, as long as the result is specific to the process in the product's life cycle.

Primary data that are not site-specific data and which have undergone third-party review, shall be used when the collection of site-specific data is not practicable.

Secondary data shall only be used for inputs and outputs where the collection of primary data is not practicable, or for processes of minor importance.

NOTE 3 In some cases, default emission factors as secondary data are not life cycle-based emission factors and require adaptation or modification.

Secondary data shall be justified and documented with references in the LCA study.

NOTE 4 This subclause is adapted from EN ISO 14067:2018, 6.3.5.

7.3.1.2.4Time boundary for data

The time boundary for data is the time period for which the quantified figure for the assessment is representative and shall be specified and justified.

The choice of the time period for data collection should consider intra- and inter-annual variability and, when possible, use values representing the trend over the selected period.

NOTE This subclause is adapted from EN ISO 14067:2018, 6.3.6.

7.3.1.3 Life cycle inventory

7.3.1.3.1General

To keep the same consistency of the LCA approach in bio-based and fossil-based product systems, the same level of detail for the inventory data should be applied.

7.3.1.3.2Data collection

The qualitative and quantitative data for inclusion in the assessment shall be collected for all unit processes that are included in the system under study. The collected data, whether measured, calculated or estimated, are used to quantify the inputs and outputs of a unit process. Significant unit processes shall be documented in the report.

NOTE This subclause is adapted from EN ISO 14067:2018, 6.4.2 and EN ISO 14044:2006, 4.3.2. For further guidance, see EN ISO 14044:2006, 4.3.2.2.

7.3.1.3.3Validation of data

A check on data validity shall be conducted during the process of data collection to confirm and provide evidence that the data quality requirements specified in 7.3.1.2.3 have been met.

Validation should involve establishing mass balances, energy balances and/or comparative analyses of emission factors or other appropriate methods. As each unit process obeys the laws of conservation of mass and energy, mass and energy balances provide a useful check on the validity of the description of a unit process.

NOTE This subclause is adapted from EN ISO 14067:2018, 6.4.3 and EN ISO 14044:2006, 4.3.3.2.

7.3.2 Reference product

7.3.2.1 General

Comparing the results of different LCA or LCI studies is only possible if the assumptions and context of each study are equivalent, see Clause 6 for details on how to determine equivalence. Comparisons between systems shall be made on the basis of the same function(s), quantified by the same functional unit(s). Special provisions on the functional unit apply to comparisons and especially comparative assertions disclosed to the public.

Functional unit is the basis of comparison. Reference flows for each product system under comparison are accordingly defined to fulfil the function expressed by the functional unit.

The comparison shall not be performed on a specified weight or volume basis (e.g. 1 kg of fossil-based product vs. 1 kg of bio-based product) unless the materials are chemicallyidentical. The comparisonshall instead be performed on the basis of function (e.g. when comparing different carrier bags, the functional unit is "to carry a certain volume of grocery shopping"). Consistency is crucial when defining the functions, functional units and reference flows, the system boundaries, and the requirements on representativeness (time-related, geographical and technological).

The functional unit of the compared systems shall be defined during the goal and scope phase.

When defining the primary function of a product, an accurate analysis of the context is necessary to avoid incorrect comparisons.

See A.3 for two examples on how find an appropriate reference product.

7.3.3 Emerging technologies

7.3.3.1 General

EN ISO 14040 and EN ISO 14044 fully apply to LCA of emerging technologies. However, emerging technologies require additional considerations that can be intuitive to experienced LCA practitioners, but which are not explicitly defined in these standards. Thus, further guidance is provided to enable comparisons between products with different levels of maturity.

In comparative analyses between bio-based and fossil-based products, the comparisons are sometimes between a new emerging technology for the bio-based product system and an existing, matured fossil-based product system. Different levels of maturity can be found in each step of the product life cycle (i.e. feedstock extraction, production, conversion, transportation, distribution and end-of-life). This can lead to situations where wider error margins can be expected and considered when comparing the product systems. The assessment of new technologies often come with higher uncertainties, but this does not mean that it is not possible to compare them with traditional technologies with more precise primary data.

Other typical challenges related to modelling of emerging technologies can include:

— lack of data;

— scale-up;

— identification of valid reference system to which to compare; and

— uncertainties related to potential future development of technology and market conditions.

Forecasts should be developed, and potential future improvements can be estimated by using scenario analyses. Uncertainties and sensitivities shall be assessed. It is important to identify all relevant parameters influenced by the development to create transparent and complete scenarios for emerging technologies.

7.3.3.2 Goal and scope

Technology readiness level for an emerging technology as well as its potential to develop should be defined in the goal and scope phase. The consideration that also established industrial scale technologies are expected to change over time shall be takenintoaccount.Temporaldevelopmentsshall be considered for both systems to reach meaningful comparison.

Geographical context shall be defined in the goal and scope.

NOTE This is especially relevant if the assessment is based on lab or pilot scale technology and the production facilities have not yet been established. Geographical location can have a significant impact on some results (e.g. water related impacts).

7.3.3.3 Life cycle inventory

When assessing an emerging technology that has been realized at lab or pilot scale, it shall be considered that the primary data gathered at these scales is not directly applicable to the industrial scale version of the system. These data are also not suitable to be used for comparison with mature fossil-based systems. To estimate the representative life cycle inventory data for industrial scale, a process system diagram should be prepared considering the full process at anindustrialscale. Specialcare andconsiderationshall also be taken when background or secondary data choices are made (i.e. applicability of data sources).

The optimization of the design, equipment and recovery and utility systems at large scales can all lead to efficiency improvements which are not possible at smaller scales. Such possible improvements in efficiency should be accounted for to properly inventory the material and energetic inputs and outputs of the system. However, for lab-scale technology, scale up can also come with operational and technical issues.

The estimation of the technology at a larger and more mature scale is referred to as upscaling. Different upscaling approaches are available to facilitate the development of representative LCI data. The appropriate approach is dependent on the availability of data and tools for assessment by the LCA practitioner. The most accurate representation is achieved through process simulation using available software tools for this purpose. The feedback of the technology developers should be incorporated when setting up the inventory table, considering the reasonable estimations of development of a specific technology.

7.4 Guidance and requirements on specific aspects when comparing bio-based and fossil-based systems

7.4.1 Resource-related aspects

7.4.1.1 Feedstock sourcing

7.4.1.1.1General

In LCA studies comparing bio-based and fossil-based product systems, the sourcing of feedstock or raw material (e.g. oil, wood or crops) can be the dominating or discriminating step.

While comparative LCA studies can be useful, it should be noted that the studies do not give a full picture as they consider only part of the relevant sustainability aspects related to responsible feedstock sourcing. Social and economic aspects are typically missing and there are other environmental aspects which are better covered in other types of assessments which allow for more qualitative reporting.

Such comparative LCA studies of products can be complemented by making social life cycle assessment or including the outcome of responsible sourcing assessments.

The outcome of responsible sourcing standards and certificates are sometimes addressed as a qualitative topic which adds an additional information layer. However, the evidence of fulfilling such sourcing standards, and the data obtained by applying them, can inform all four phases of an LCA.

The outcome of these responsible sourcing schemes can be used in two different ways:

a) As a source for data collection for the LCI.

b) Become an integral part of the interpretation phase.

However, the key issue here is that these responsible sourcing standards do exist for bio-based materials but are largely missing for fossil-based resources. To have a full comparison of all aspects related to responsible sourcing, such data would be needed for both product systems. When these data are only available for bio-based materials, this blocks a more comprehensive comparisons between bio-based and fossil-based product systems and keep it limited to the environmental inputs and outputs normally covered by an LCA.

There are three standards related to bio-based products which refer to responsible sourcing, namely EN 16760, ISO 22526-4 and EN 16485.

In short, the concept of complementing LCAs with responsible sourcing assessments is not developed in LCA. When it is incorporated as an additional source for data collection in LCI only for bio-based product systems, this could lead to unbalanced comparisons and conclusions.

7.4.1.1.2Goal and scope

Data quality shall be defined in the goal and scope phase and, using responsible sourcing assessments as a source for additional data collection for a LCI is encouraged. It should not lead to a more biased LCA, e.g. in cases when data can only be collected for the bio-based products.

7.4.1.1.3Life cycle inventory

During the inventory phase responsible sourcing standards can deliver direct or indirect information on elementary flows.

Direct information can relate to the use of certain chemicals, e.g. certain pesticides are prohibited. These may then be excluded as flows from the corresponding outdated LCI data set. Indirect information can relate to implicit outcomes on carbon flows by land transformation; some certification schemes do not allow transformative land use inthe recent past. This canthenalso overlap with the requirements related to GHG emissions from land transformation.

However, by including this additional information more data are handled in the LCI of the bio-based product, which can lead to higher impact assessment values, while corresponding data are missing in the fossil-based LCI. In this case information asymmetry places the bio-based materials at a disadvantage. Such asymmetries can be addressed with justified and transparently reported estimates of impacts for the product or value chain where corresponding data are missing. Where reasonable estimates cannot be drawn, the LCA study in the interpretation should report available and missing data, which introduces an asymmetry between compared systems. Then, the interpretation should be balanced in light of that asymmetry, while using sensitivity analyses.

7.4.1.1.4Impact assessment

Impact assessment methods that connect to land use types implicitly assume certain management techniques and related averages. Applied sustainable or responsible sourcing standards can deliver evidence to check the assignment of characterization factors to specific land uses.

7.4.1.2 Land use

7.4.1.2.1General

Impacts associated with land use and land use change are increasingly recognized as important aspects to consider when conducting LCAs as this is linked to major ecosystem services (e.g. regulating services, cultural services, supporting services, wellness services and provisioning services). Both the sealing of land by construction, infrastructure and industrial use (e.g. oils and minerals) as well as agricultural and forestry activities, lead to a change in the natural soil functions and thus the originally provided ecosystem services.

Land use has two aspects, land occupation and land transformation. These can both have positive or negative effects on e.g. biotic production potential, biodiversity, ecological soil quality, soil carbon content, soil erosion and freshwater availability. Land use is associated with physical and chemical impacts on the soil and therefore on its fertility or production potential. Potential impacts due to land use are captured in impact categories such as freshwater eutrophication, terrestrial acidification or climate change. Over the last years the impact of anthropogenic pressure on the soil system has been integrated into life cycle impact assessment models (see Annex C[4]), even if a balance between complexity and comprehensiveness and their applicability is still to be found. In particular, the excessive complexity of relations among anthropic, natural, chemical, climate etc. factors and their site-specificity represent the main challenge to overcome. When there is a change in the land use (e.g. the shift from forest land to cropland or the shift from an annual crop agricultural area to poli-annual agricultural area), a land use change canoccur which can induce changes in related indicators (direct, indirect land use or others). This canleadtocarbonstocksinsoiltobepositivelyornegativelyaffected.Theinducedchangeinturndirectly affect the GHG calculation/emissions of the analysed product system.

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.

7.4.1.2.2Goal and scope

Current land use LCIA frameworks build on the following:

— the inventory of land use is quantified in the elementary flows "occupation" [m^2a] and "transformation from/to" [m^2]; and

— land use impacts are calculated using characterization factors on country level for various land use types.

Land use and land use change has a direct impact on the amount of carbon stored in the soil and above ground, thus it directly affects greenhouse gas inventories and the related life cycle assessment.

There is currently no agreed scientific method to characterize indirect land use change in conformance with the modelling principles of LCA. Hence, addressing GHG emissions, consideration of potential effects from indirect land use change can only be addressed during the interpretation phase. On the contrary GHG emissions and removals occurring as a result of direct land use change (dLUC) within the last decades (the period of 20 years is generally used) shall be assessed in accordance with internationally recognized methods, like IPCC and documented separately in the study report. Possible GHG emissions

4 Land use models that do not have characterization factors associated to land use flows are not taken into account.

and removals occurring as a result of land use (e.g. increase of carbon stocks in soil due to the increase of amount of biomass left in soil) should be included and documented.

7.4.1.2.3Life cycle inventory

The life cycle inventory input data for determining the potential impact of land use generally consists of:

— land use type;

— location;

— duration of land use;

— area;

— land management (e.g. input of fertilizers/chemicals, tillage system, irrigation and drainage, rotations); and

— evidence that further qualify land use types (such as the restricted use of fertilizers or chemicals).

Responsible sourcing standards can be used to prove that no land use change has taken place; see 7.4.1.1.

Biomass production through agriculture and forestry typically uses larger areas of land than the production of e.g. fossil oil. However, the way the land used is affected should also be considered as well as the effects of eventual accidents (e.g. oil spills or uncontrollable forest fires). When no inventory data are readily available, a new inventory should be performed.

Clause A.4 includes examples of inventory data related to the land use.

The GHG emissions associated to the LUC can be determined through the estimation of soil C stock variation, that is, as the difference betweenthe amount of SOC_0 and $SOC_{(0-T)}$where 0-T refers to 5 years, 10 years or 20 years ago. In absence of accurate models (e.g. based on site-specific data and parameters) the Volume 4 of IPCC guidelines [21] provides three levels of assessment for agricultural, forestry and other land use. Tier 1 corresponds to the basic method, frequently utilizing IPCC-recommended country-level defaults, while Tiers 2 and 3 are more demanding in terms of complexity and data requirements.

7.4.1.2.4Impact assessment

The methods reported in Annex C can provide highly heterogeneous results. Some of the methods (e.g. Brandão and Milà i Canals [31]) provide indicators for specific soil properties (e.g. SOM), while others (e.g. Saad et al. [45]) allow to assess one or several soil threats (erosion potential, desertification, etc.), and other methods (e.g. LANCA [30]) consider the provision of ecosystem services based on soil functions. In all cases the inventory data are multiplied by country-specific characterization factors (CFs) to obtain the metric for accounting land use impacts in the LCA. The higher the result, the worse the environmental load caused to land. Some methods require verycomplete and site-specific inventory data for which collection can be more demanding.

The CFs of the globally applicable models do not sufficiently differentiate between diverse types of land use (including intensity) or between different management practices. Also, these CFs rely heavily on the choice of reference scenario, which add uncertainty. Consequently, current land use methods are unable to evaluate e.g. different agricultural or forest management practices. Nevertheless, the evidence of responsible sourcing of biomass (see 7.4.1.1) can provide useful complementary information for environmental qualification. GHG emissions from dLUC can be screened by using the IPPC methods [19-21].

7.4.2 Reuse and end-of-life aspects

7.4.2.1 Reuse

Reuse of a product can have a significant bearing on its life cycle environmental impacts: this is true both when the subject of the investigation is itself a reused product, and when it is a new product that is intentionally reusable.

For the purpose of this discussion, reuse occurs when a product is used again for a similar purpose or function (whether or not in the same ownership) without undergoing significant transformation or remanufacturing beyond, for instance, cleaning and minor repairs. Significant transformation or remanufacturing of a product should, however, be considered end-of-life, and therefore assessed as a form of recycling (which should be modelled accordingly, taking account of the processes involved).

For products designed for multiple reuses, excluding long-lasting constructionproducts, a stated number of reuses may be treated as a normal part of the product life. In this case, reuse is therefore not treated as an end-of-life option but as an extension of its modelled service life, extending its utility, and reducing the impacts associated with the functional unit. For comparisons of reusable products, the number of times reused is a key variable.

NOTE EN 15804 sets requirements on how to treat reuse for construction products.

7.4.2.2 End-of-life

7.4.2.2.1General

When modelling end-of-life (EOL) of bio-based and fossil-based products, various issues can be taken into consideration.

The following end-of-life options are of relevance for both bio-based and fossil-based products, and can be considered in an assessment to show their potential:

— mechanical recycling (including solvent-based recycling);

— chemical recycling (depolymerisation, pyrolysis and gasification);

— organic recycling (industrial composting, anaerobic digestion);

— home composting;

— incineration, with or without energy recovery;

— landfilling;

— controlled release in nature (agriculture);

— littering and uncontrolled release in nature are not end-of-life options, but since they widely occur they may be considered on a case-to-case basis. (See 7.4.3.2.)

Depending on the material, the application and the existing end-of-life infrastructure it is necessary to make a careful assessment of which end-of-life option(s) should be included. The assessment should include clearly stated assumptions concerning the distribution of the waste stream between the EOL options, and ideally should test the sensitivity of results to variations in this distribution.

Reuse is not an EOL option but shall also be considered in comparative LCAs.

In LCA there are two options on how to model EOL:

— Option 1: the modelled end-of-life options represent the ideal, optimum situation(s), not reflecting the actual situation. The objective here is to investigate the EOL options reflecting the best environmental outcome possible.

— Option 2: the modelled end-of-life options represent the actual situation. This is often a mix of different EOLoptions. It describes thecurrent situation, concerning EOLof theproductsinvestigated.

NOTE Local, regional, or national waste disposal regulations can inform the choices made, especially in option 2.

Both options can be used, as appropriate to the goal of the study, but they should be used in a consistent way for all products investigated. A combination of option 1 and 2 can be used in an LCA to show the potential of further optimizing the EOL of a specific product.

Depending on the goal and scope of the study, considering also burdens of whole waste steam e.g. food waste can be relevant, but not for all cases.

Products which are biodegradable in industrial composting facilities can in some cases also be mechanically or chemically recycled, which should be considered when modelling the EOL.

7.4.2.2.2Goal and scope

Many bio-based products do have multiple EOL options such as industrial composting and mechanical and chemical recycling. However, many LCAs looking into biodegradable or compostable materials often only focus on composting as the only end-of-life option, and do not include the option of mechanical or chemical recycling. Depending on the material, the application, and the existing end-of-life infrastructure, a careful assessment on which end-of-life option(s) to include shall be made and the intended use of the results of the LCA study shall be stated in the goal and scope of the study, explaining the inclusion or exclusion of specific end-of-life options.

When compostable bio-based products are compared with their fossil-based alternatives, the LCA should be modelled in such a way, via selecting the proper functional unit, that the composition of the actual waste stream, in which the product under investigation occurs, is reflected in the analysis. This is further explained using a few examples in A.5.

If the purpose of the study is to investigate multiple functions of end-of-life systems, this shall be stated in the goal and scope of the study.

EXAMPLE Only comparing the possible versions of a tea bag material with each other is oversimplifying reality, one also needs to include what to do with the tea waste and the net avoided microplastics when converting the tea bag into one designed to facilitate composting.

7.4.2.2.3Life cycle inventory

If multiple end-of-life scenarios are included in an LCA of a specific product, the LCA of the product under investigation should be modelled in such a way that the model describes the end-of-life situation as close as possible to reality.

It should be taken into consideration that end-of-life options differ in different parts of the world. Whereas some countries have a well-established mechanical or organic recycling infrastructure, others still rely on landfilling or no management at all. Here the biodegradation properties of a product can become relevant, and proper modelling of aerobic and anaerobic digestion of biodegradable carbon should be applied.

7.4.2.3 Residues and wastes as feedstock

Guidance for when residue and wastes are used as feedstock can be found in A.6.

7.4.3 Emerging impact categories

7.4.3.1 Biodiversity impacts

7.4.3.1.1General

Impacts on biodiversity can be relevant in the context of this document when comparing bio-based and fossil-based products as biodiversity loss drivers (i.e. climate change, environmental pollution, water use) are connected to both product systems.

Biodiversity impacts can be caused by emissions to soil, water, air and by certain land/water using activities.

Duetothedifferencesinfeedstockproductionandduetothedifferencesinend-of-lifetreatmentbetween bio-based and fossil-based products, significant differences in biodiversity impacts can be observed for both land-using activities and the entire set of biodiversity loss drivers. The same LCA impact categories and methods shall be applied to both types of feedstocks when comparing product systems.

International consensus on a method capturing biodiversity impacts considering all possible drivers within a single impact category has not been reached, nor on how to aggregate the effects of individual impact categories contributing to a potential impact on biodiversity.

Biodiversity impacts related to land use are currently typically being measured either as property of a land use type in a certain geography (referred to as ecosystem function) or as property of the biosphere or natural environment (ingeneral biomes, ecoregions, etc). To get a comprehensive view onbiodiversity impacts, not only land use should be taken into account, but also e.g. losses as a result of climate change.

Biodiversity impact assessment can take place on midpoint level or on end point level in the LCA study's impact assessment.

Three examples of approaches for land use impact assessment are given in A.7.

7.4.3.1.2Goal and scope

Ingoalandscope,itshouldbeevaluatedwhetherbiodiversityimpactisrelevantfortheproductsinscope.
If covered, it shall be specified for both the bio-based and fossil-based product system, which biodiversity impact will be considered in the study, and which method to be used.

7.4.3.1.3Life cycle inventory

Information about certification schemes related to responsible sourcing, land management practices or any other information related to biodiversity impacts of the processes under study shall be documented.

NOTE In case land use is addressed, biodiversity related land use inventory requirements are defined in 7.4.1.2 on land use.

7.4.3.1.4Impact assessment

Biodiversity impacts should be considered in LCIA phase when validated methods and applicable data are available.

7.4.3.2 Microplastic emissions

7.4.3.2.1General

The problem of pollution from plastics released in the environment is one of the most relevant subjects of numerous debates, studies and legislation initiatives at international level [18, 22, 23]. The microplastics that are produced from the partial degradation of plastic objects exposed to the environment arouse particular concern for their tendency to accumulate, for the impossibility to be collected and therefore the risk that they come into contact with living beings with consequences that are

still not well known today. Plastic leakages occur along the whole product value chain, including at the use stage particularly for textile products during washing, but also at the disposal stage of the product where the likelihood of release in the environment is often the highest. When a plastic item is exposed to the environment it undergoes environmental degradation, which leads, sooner or later, to the formation of microplastics. The greater the amount of microplastic and the longer the residence time in the environment, the greater the chemical and physical risk to the biota. Characteristics such as the biodegradability of a material can mitigate the problem, ensuring a shorter permanence in the environment.

While the impact of microplastic emissions could be accounted within LCA methodology when the cause-effect relationship between microplastic and biota and human health will be clearer, it is already possible to characterize and quantify the exposure of the biota to microplastics. A suggested methodology is further described in A.8.

NOTE 1 The proposed methodology (informative) provides characterization of materials on the basis of their potential to release persistent microplastic in the environment. The methodology is based on the intrinsic properties of the material, and it is not intended to quantify the release of microplastics along life cycle of a product nor their impacts on biota and human health (despite the persistence is a relevant information in risk assessment as it is related to the exposure).

NOTE 2 Microplastics identify small (<5mm) particles made of plastic. However, the methodology is not specific for plastic, but it can be applied to any solid material. For example, the MPEP let practitioners differentiate natural fibres like cotton compared to (not natural) polymeric fibres on the basis of the persistency of the microplastics released.

7.4.3.3 Indirect effects including iLUC

7.4.3.3.1General

Indirect effects are the expected or potential consequences of the investigated product supply chain on other product systems. Such effects can include either market-mediated effects, or effects that are not easily put in direct relation with a specific supply-chain activity. Even though the quantification of many indirect effects is not to be included in an LCA study, or are subject to a too high level of uncertainty to be used for a reliable assessment, it can be considered appropriate to mention and evaluate the available information, but only as additional information reflected in the limitations. Before considering including indirect effects in the LCA study, the question to be answered is if the effect also actually takes place.

Examples of indirect effects for both bio-based and fossil-based products can be found in A.9.

When comparing the life cycles of bio-based products with fossil-based products, a consistent approach should be applied when taking into account specific indicators or effects, including, but not limited to, indirect effects. However, the inclusion of indirect effects comes with a number of issues:

— Indirect effects are taking place outside the system boundary of the comparison.

— Itisoftennotclearexactlywheretheassessmentoftheindirecteffectsstops;oneoftenhasadditional indirect or direct effects of the original indirect effect.

— The inclusion of indirect effects can often, if not always, lead to double counting.

The inclusion of indirect effects is therefore better suited in a specific, detailed study on a single product system than in a comparison between products.

If indirect effects are presented in an LCA study, the collected data shall only be presented as additional information. The results of the indirect effects shall not be added up by the result of the LCA.

7.4.3.3.2Goal and scope

Before including indirect effects in the goal and scope of an LCA, the study shall provide an assessment of the level of risk that the indirect effect studied occurs.

7.4.3.3.3Life cycle inventory

If it is decided that indirect effects will be included in the LCA study, then they shall be included in a consistent way for both the bio-based and the fossil-based product.

Indirect effects shall only be included if generally accepted methods are available.

8 Guidance and requirements for interpretation and reporting

8.1 General

General guidance and recommendations on how to evaluate the environmental impacts of products and services are provided by international standards for LCA (EN ISO 14040 and EN ISO 14044) and carbon footprint of products (EN ISO 14067). Further, EN 16760 applies the two LCA standards to bio-based products, adding specific requirements and guidance. These four standards also provide further requirements when studies compare different systems, and it is important that compared systems are handled consistently to make it possible to take well-informed decisions about the outcome of the LCA study.

However, there are several details that are specifically relevant for comparison of the life cycle of bio-based and fossil-based product systems which are not addressed satisfactorily in the above-mentioned documents which have been raised in this document. In the case of comparison between such systems, the interpretation phase of an LCA study is of utmost importance to cover data asymmetries and enable proper conclusions. Therefore, the following LCA study report and third-party report shall be comprehensive and transparent, with clear descriptions and justifications of methodological choices for the particular study and well-documented actions taken for the interpretation phase.

8.2 Normalization and weighting

LCA studies containing a comparison between bio-based and fossil-based product systems can show an environmental performance profile which is inconclusive without any type of additional weighting or ranking. Examples are e.g. land use related impacts that are typically large for feedstocks for bio-based product systems versus ecotoxicity impacts in the marine environment for fossil feedstock systems.

Following LCA standards all impact potentials shall be interpreted and reported separately. Normalization and weighting are optional and additional steps that help to substantiate conclusions. For a comparative assertion, normalized and weighted results shall not be used for presenting final results.

If numerical data are used, special attention should be paid on the completeness corresponding to all impact categories and also related to relevant LCI data that is not treated in LCIA such as the evidence of management practices following a performance standard.

Incomparing the lifecycles of bio-based products with their fossil-based equivalents inLCA,current LCIA methods can deliver a contradicting LCIAprofile at the end of the impact assessment. This includes trade-offsbetweenalternatives– but canalso be informedbydocumentedmodelling choices,data asymmetries and data gaps.

Contradictions can be observed, e.g.:

— Depending on the methods chosen, indicator scores can also contain an implicit double counting for biodiversity-related end points such as acidification potential or eutrophication potential.

— Incomplete characterization models for categories like material use and the corresponding contributions to e.g. abiotic depletion potential are difficult to interpret and contextualize.

Normalization and weighting can be an additional step in the LCA process to come to well informed conclusions. However, normalization and weighting can come with significant shortcomings, since all data will be aggregated into one number, and all nuance disappears for the interpretation. Whenapplying normalization and weighting the following aspects should be taken into consideration:

a) Which set of factors should be used? How do they compare with other sets?

b) How representative are theytodayforthegiventimeboundaryspecified for the LCAstudy? And even more important, for the years to come? In many LCAs directions are given for future decisions, e.g. which packaging should be used for the next 5 years. So, the factors should not be obsolete, but valid for the years to come.

c) What is the geographical boundary for the normalization and weighting boundaries?

The following steps should be taken to address the above issues:

— Data categories should be chosen in view of potential weighting / normalization steps.

— If the study is intended to fully include the three end points (human health, ecosystems and natural resources) data gaps should be closed, and asymmetries should be removed in order to allow proper impact modelling.

8.3 Interpretation

8.3.1 General

Inthe interpretationphase of a life cycle assessment, the findings of theinventoryanalysis and the impact assessment shall be used to identify significant issues. The findings shall be evaluated in relation to the defined goal and scope in order to reach conclusions, limitations and recommendations.

This evaluation is intended to establish confidence in the results of the LCA study and is especially important when comparing systems with many basic differences (e.g. feedstock, end-of-life).

The evaluation includes completeness check, sensitivity check, consistency check, and any other validation that can be required according to the goal and scope definition of the study.

NOTE For additional guidance on completeness, sensitivity check and consistency check, see EN ISO 14044:2006, 4.5.3.2, 4.5.3.3 and 4.5.3.4, respectively.

For comparing bio-based products with their fossil-based equivalents in LCA, care should be taken to distinguish interpretationand conclusions including discussions on trade-offs between alternatives from interpretation and conclusions that relate to incomplete life cycle inventories or inherent limitations of impact assessment approaches (see 5.7).

Next to investigating the impact of modelling choices, the interpretation phase typically covers the discussion of significance of observations made during LCI and LCIA and relevance of a difference between two impact potentials in the LCA study.

Such interpretation of the LCIA profile can deliver and support robust conclusions.

For the aspects listed in Clause 6, this clause provides further guidance and requirements to make fair and correct comparisons between bio-based and fossil-based product systems.

Guidance and requirements can be found for these aspects to consider in the following subclauses:

a) modelling considerations for carbon flows (8.3.2);

b) biogenic carbon storage in products (8.3.3);

c) emerging technologies (8.3.4);

d) feedstock sourcing (8.3.5);

e) land use (8.3.6); and

f) biodiversity impacts (8.3.7).

8.3.2 Modelling considerations for carbon flows

When a study compares, or is intended to be used as a basis to compare, fossil-based and bio-based product systems the treatment of biogenic and fossil carbon flows in inventory analyses, impact assessmentsandinterpretations shall be considereda significantissue.The followingsensitivityanalyses should be part of the interpretation phase and the scope and scale of these analyses shall be clearly described in and reported transparently in the LCA study report:

— sensitivity analyses sufficient to reveal and explore the impact of adopting different approaches to treatment of carbon flows in the inventory and in impact assessment:

  — e.g. a scenario where the net impact of biogenic CO_2 flows is attributed to the product system under study; and

  — e.g. a scenario where the net impact of all fossil CO_2 elementary flows that can eventually be released to the atmosphere are attributed to the product system under study.

8.3.3 Biogenic carbon storage in products

The temporal profile of the emissions and the period of storage of carbon in the product used as input in the LCA are assumptions and can differ from the actual period of storage. Therefore, sensitivity analysis on the assumptions of the delayed emissions should be performed.

8.3.4 Emerging technologies

Potentially increased uncertainty of results due to emerging technology shall be considered and evaluated. All identified sources of uncertainty shall be stated.

Special attention to sensitivity analyses shall be given in situations where there are foreseen possibilities for product systems to develop (e.g. parameters identified that are expected to change in future).

The results of uncertainty analysis and data quality analysis should supplement these checks (EN ISO 14044:2006, 4.5.3.1).

8.3.5 Feedstock sourcing

Responsible sourcing of bio-based raw materials, when proven with existing certificates from a relevant internationally recognized standard or certification system, shall be reported together with the outcome of the LCAstudy. This shall be a part of the final evaluation. This outcome shallbe discussed together with conclusions from studies conducted on the fossil resource production to draw final, informed conclusions.

Theinterpretationof suchevidencecanhelp to contextualize impact potentials and inform the discussion of significance and relevance for land use related matters and ecosystem and natural resources related end points.

A caveat in using data from organizations applying responsible sourcing standards is that there can be higher reference flows resulting from less intensive land use practices e.g. by set-aside requirements in forestry or in agriculture (e.g. to maintain or improve biodiversity conditions), as the amount of occupied land is typically larger. This effect shall be considered in the interpretation of the LCIA profile and be comprehensively reported.

If responsible sourcing certificates and documented practices are mentioned in the final assessment for the bio-based product, and corresponding data are not available for the fossil-based alternative, then this should be explicitly mentioned.

8.3.6 Land use

In the comparison between bio-based and fossil-based product systems, land use change emissions do not only occur in the production of agricultural and forestry products, but also from other product systems e.g. emissions related to fossil related production infrastructure and processing plants. A consistent approach and the same level of accuracy should be applied in the LCA study for both product systems.

Many fossil-based products can have issues with LUC, mainly in the production of the raw materials e.g.:

— oil from tar sand production;

— pollution of soil due to oil extraction;

— equipment occupying the land due to long term oil production using pumpjacks; and

— linked to oil fracking.

The contribution of soil organic carbon (SOC) in mitigating GHG emissions is largely recognized e.g. carbon farming is a reality and can contribute significantly in the efforts to mitigate climate change [38] and therefore, soil carbon uptake shall not be excluded a priori.

Bio-based products can have both positive and negative LUC impacts. The land use impacts can be positive, as a result of increased soil carbon storage due to e.g. improved agricultural practices like reduced tilling and the application of cover crops.

NOTE Responsible sourcing standards can be used to prove that no land use change has taken place; see 8.3.7.

8.3.7 Biodiversity impacts

During interpretation phase impacts on the natural environment and biodiversity should be assessed either based on quantitative LCIA data and/or on qualitative information from LCI including evidence related to relevant internationally recognized standards or certification systems.

It should be explained where in the life cycles of both the bio-based and fossil-based product systems emissions or activities impact the biodiversity.

Bio-basedsystems typicallyshow different land transformationand occupationpatterns whencompared with equivalent fossil-based systems. It follows then that, where biodiversity impacts are based on land use types, the bio-based system will also tend to show higher potential biodiversity impact values with the currently used methods. Unless other potentially significant contributors to biodiversity impact such as GWP are also considered (e.g. through use of a suitable end point method), land use related biodiversity impacts shall not be confused with a comprehensive overall relative impact on biodiversity. Care shall be taken to ensure that results are interpreted and reported clearly, accurately, and transparently.

8.4 Reporting

8.4.1 General

When a study compares or is intended to be used as a basis to compare fossil-based and bio-based product systems, the study report and third-party report shall include the interpretation and associated sensitivity analysis with full transparency.

All choices and assumptions, including applied methodologies, shall be justified, and documented in the LCA study report.

8.4.2 Additional requirements and guidance for third-party reports

When results of the LCA are to be communicated to any third party (i.e. interested party other than the commissioner and the practitioner of the study), regardless of the form of communication, a third-party report shall be prepared.

The third-party report constitutes a reference document and shall be made available to any third party to whom the communication is made. The third-party report can be based on study documentation that may be excluded from the third-party report.

NOTE The text above is based on the first three statements in EN ISO 14044:2006, 5.2.

8.4.3 Quantification of removals and emissions of biogenic and fossil carbon

When performing cradle-to-gate studies, information on the biogenic and fossil carbon content of the reference flow shall be documented separately (for details, see EN ISO 14067:2018, 6.4.9.8, including Figure 3). This information is relevant for the remaining value chain. It allows to calculate biogenic and fossil carbon emissions and removals when the intermediate product is used in a final product and a cradle to grave study is to be carried out.

Both biogenic and fossil GHG emissions and removals shall be included and shall each be reported separately in both cradle to gate and cradle to grave assessments. Both for cradle to gate and cradle to grave, also a net GWP value (sum of emissions and removals) may be reported.

8.4.4 Biogenic carbon storage in products

Where accounting of delayed emissions due to biogenic carbon storage in products has been done it shall be reported separately, clearly defining the methodology used, time horizon and additional assumptions made.

8.4.5 Data requirements and sources

Data quality considerations shall be reported following the requirements of EN ISO 14044.

In addition, reports shall disclose data quality considerations related to:

— spatial boundaries for fossil and bio-based systems; and

— temporal boundaries for fossil and bio-based product systems.

8.4.6 Biodiversity impacts

It shall be reported if impacts on biodiversity are assessed as end points that are specifically allocated to a certain type of land occupation or transformation only or if biodiversity impacts are assessed as end point for all corresponding impact pathways.

Reporting shall include the land use type for which data has been collected:

— Midpoints or end points that are specifically allocated to a certain type of land occupation or transformation only; or

— End point if biodiversity impacts for all corresponding impact pathways.

8.5 Critical review

When a study compares or is intended to be used as a basis to compare fossil and biogenic carbon containing systems, then the critical review shall assess the completeness of the sensitivity analysis, its treatment in interpretation and the clarity and sufficiency of reporting.

Annex A
(informative)

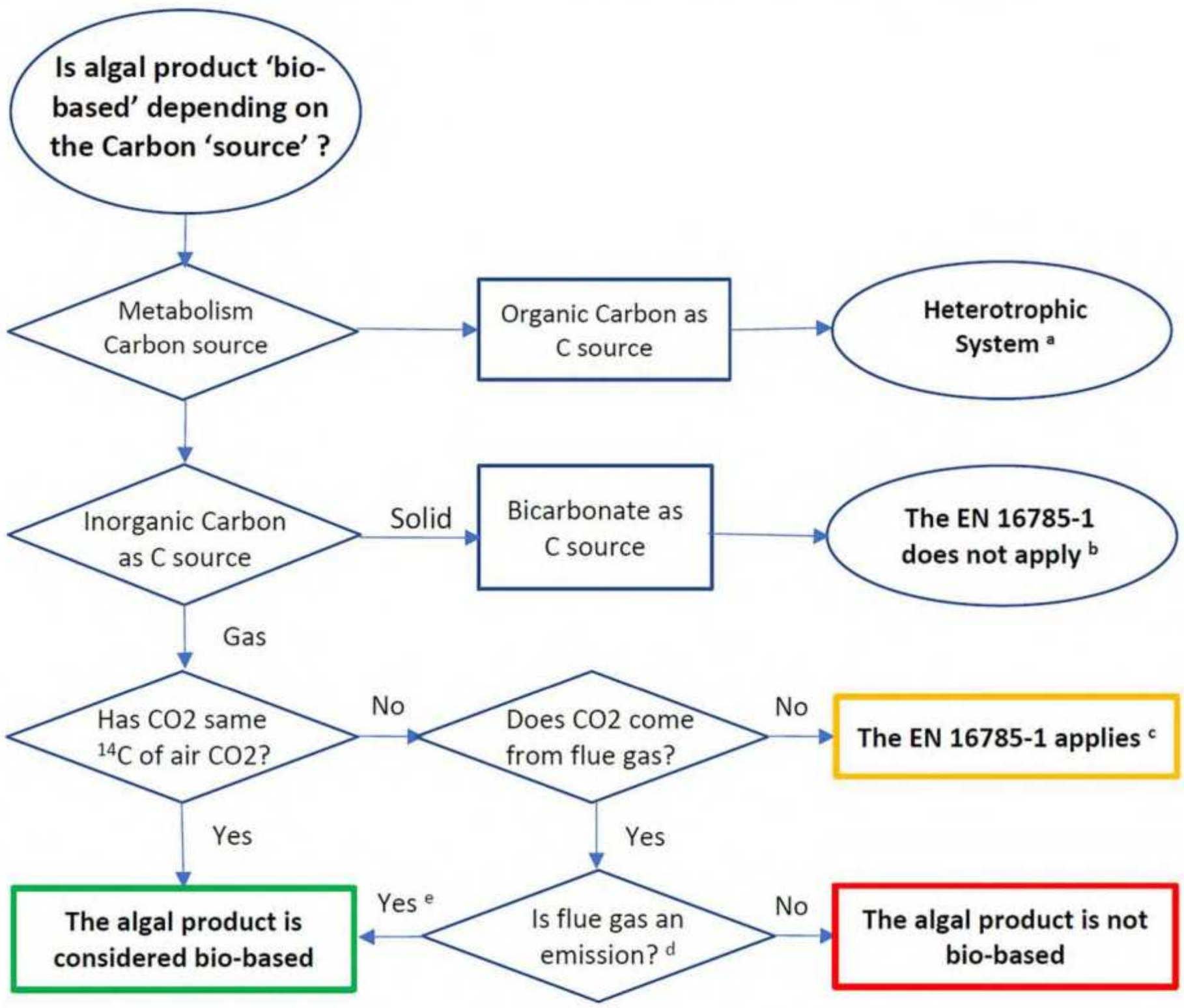
Examples related to different aspects

A.1 Guidance and examples related to modelling considerations for carbon flows

A.1.1 Algae grown with fossil CO_2

A.1.1.1 General

Algae and particularly microalgae farmed in closed systems (photobioreactors but also raceway ponds) can make photosynthesis reducing CO_2 from flue gas i.e. fossil carbon. A flow chart is given in Figure A.1 adopted from EN 17983:2024 to allocate products from such biomass to bio-based products.



Key

a mixotrophic system can be considered as combination of heterotrophic and autotrophic

b bicarbonate can come from fermentation neutralization, this is not covered in this document

c in order to apply EN 16785-2 in case of cryogenic CO_2 supply, the CO_2 shall have a source indication

d an emission is considered here the conveyed stream of gas to atmosphere "already carbon neutral"

e an "already carbon neutral" emission has carbon footprint already cleared e.g. it is not fossil carbon displaced from soil to the atmosphere for the same purpose

Figure A.1 — Flow chart for algae as bio-based products

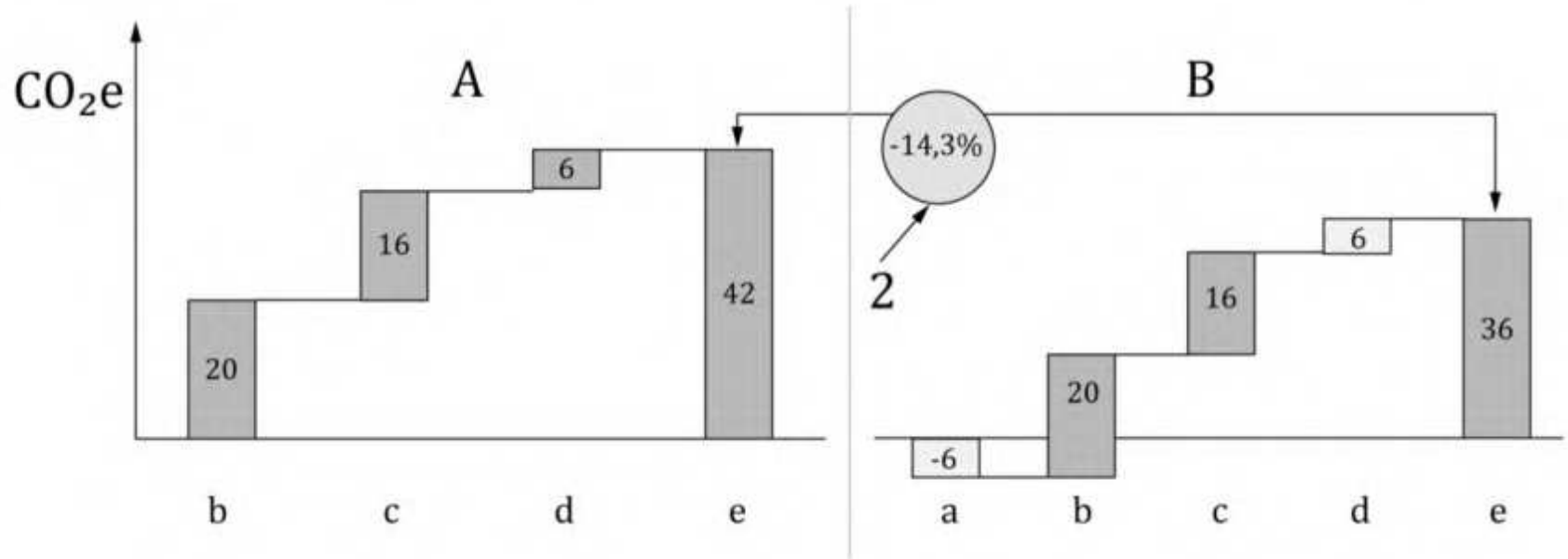
A.1.2 Examples on the impact assessment phase

Figure A.2 a) and Figure A.2 b) present the cradle to grave emissions comparing a 100 % fossil-based and a 100 % bio-based product. Figure A.2 a) gives an example where incineration is the end-of-life option for both products. Figure A.2 b) represents the end-of-life emissions via composting for a bio-based product where the biogenic emissions, unlike incineration, are not balanced since the carbon embedded in the product is not fully mineralized to CO_2 (within a 100 years' timeframe) due to humification processes. In the numerical example this amount corresponds to 8 % of the biogenic carbon in the product (i.e. 0,5 CO_2e of 6 CO_2e). No CH_4 emissions occur in end-of-life.

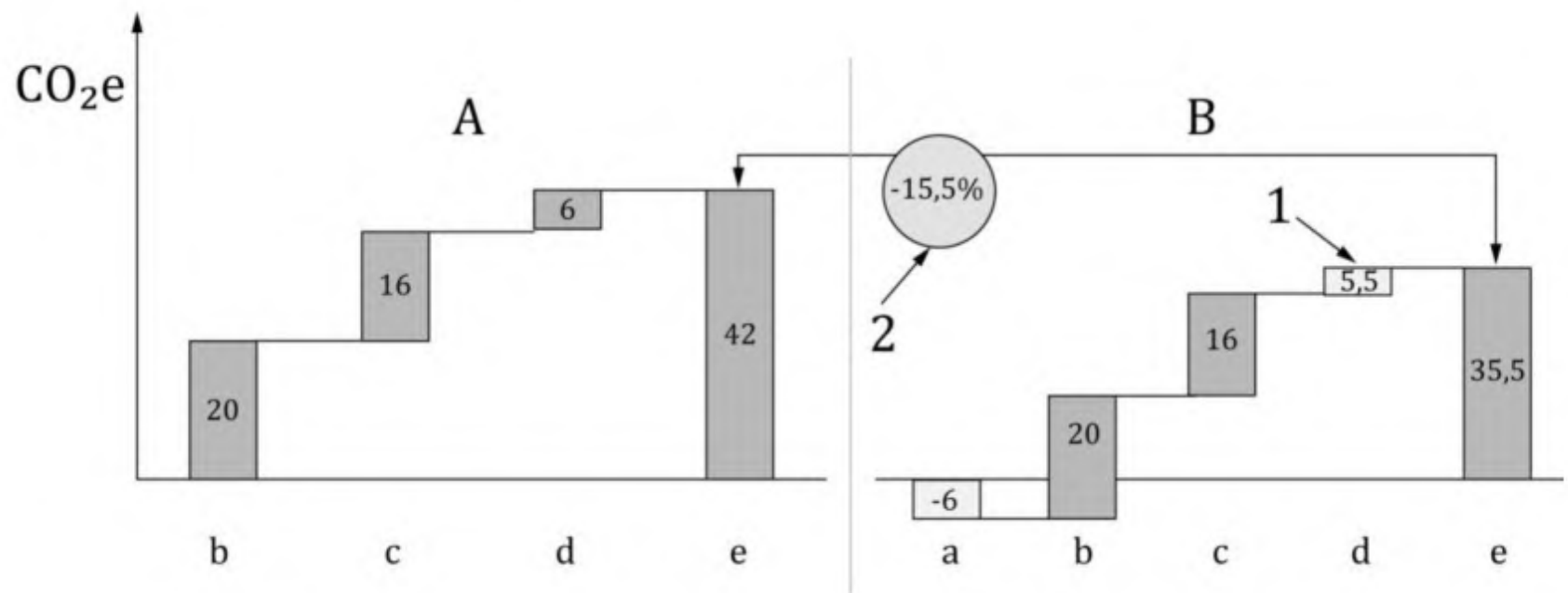
Both the fossil and bio-based products have the same carbon content, expressed as 6 CO_2e. For both products the cradle-to-gate and the downstream emissions are the same, 20 CO_2e and 16 CO_2e respectively. Total cradle-to-grave emissions for the fossil-based product is 42 CO_2e, and the total for the bio-based product is 36 CO_2e (in case of incineration) and 35,5 CO_2e (in case of composting), which gives a difference of 14,3 % and 15,5 %, respectively.

NOTE 1 This is an illustrative example and it is provided just for the sake of clarity; situations can be different in practice.

NOTE 2 Long term (>100 years) carbon sequestration from compost or digestate varies based on local conditions and other parameters. Data concerning the amount of carbon sequestration are available in literature or can be experimentally measured.



a) Both are incinerated at the end-of-life



b) The fossil-based is incinerated at the end-of-life and the bio-based is composted

Key

A : fossil-based product
B : bio-based product
a : carbon removal
b : cradle-to-gate emissions
c : downstream emissions
d : end of life emissions
e : total cradle-to-grave emissions
1 : biogenic emissions
2 : difference in emissions between the fossil-based and the bio-based product

Figure A.2 —Cradle to grave inventory for a bio-based and a fossil-based product

A.2 Example on how to calculate the temporary storage

EXAMPLE Modified from EN 16760:2015 Annex B.

Determination of temporal accounting of the bio-based product (embedded carbon: 6 kg CO_2e/kg), illustrated in Figure A.2a).Formulae A.1andA.2are usedtocalculate the carbon footprint oftemporarilystored CO_2 andthe mass of carbon stored in a product and released as CO_2 within a 100-year horizon, respectively. The bio-based product sequesters carbon for 80 years in the use phase.

$$CFP_{\text{tempStorage}} = \frac{\sum m_{CO_2} \times t_s \times GWP_{IPCC,CO_2}}{100} \quad (A.1)$$

where

$CFP_{\text{tempStorage}}$ is carbon footprint of temporarily stored CO_2;

m_{CO2} is mass of CO_2 removed;

t_s is time of temporal storage in years;

$GWP_{IPCC,CO2}$ is IPPC global warming potential for CO_2 for 100-year time horizon

$$m_{CO2} = m_c \times M_{CO2} / M \quad (A.2)$$

where

m_C	is the mass of carbon stored in a product and released as carbon dioxide within a 100-year time horizon;
M_{CO2}	is molecular weight of carbon dioxide;
M_C	is molecular weight of carbon.

Which in this example gives: $\frac{6\text{kg } CO_2\text{e} \times 80 \times 1}{100} = 4{,}8\text{kg } CO_2\text{e}$

The bio-based product illustrated in Figure A.2 a) has a total cradle-to-grave carbon footprint of 36 CO_2e/kg and realizes an additional benefit due to temporal storage of bio-based carbon of −4,8 kg CO_2e. The total net cradle to grave carbon footprint including temporal storage is 31,2 kg CO_2e.

A.3 Examples on how to determine an appropriate reference product

EXAMPLE 1 Bio-based biodegradable mulch film and fossil-based non-biodegradable mulch film.

Both films have an equivalent primary function but different end-of-life: the biodegradable mulch film is left on the ground and tilled into the soil at the end of the agricultural cycle while the non-biodegradable film needs to be removed, collected and disposed. During the removal some pieces of plastic remain in the soil (the thinner the film, the higher the risk) and conventional plastic mulching films do not biodegrade in soil and accumulate over time. Accordingly, a recommendation to only use conventional mulch film thicker than 25 µm was added into the scope of EN 13655 when revised to make sure they can be collected after use, which influences the amount of material needed to fulfil the primary function.

EXAMPLE 2 Waste bags for the separate collection of food waste.

In countries or regions, the use of compostable liners can be prescribed to avoid the contamination of collected food waste (and the compost made from it) with non-compostable bags. In this case the characteristics of the product (compostability) drives the comparison as well as the primary use.

A.4 Examples related to life cycle inventory for land use

In Table A.1 the aggregate inventory data for the production of 1 kg of maize (14 % humidity) in US and 1 kg of light fuel oil in Colombia are shown. The data in the table is not intended for comparison but as two examples of inventory data regarding one bio-based and one fossil-based feedstock. The two feedstocks might not have the same final applications.

Table A.1 — Inventory data on land occupation and land transformation related to 1 kg of maize produced in US (14 % humidity) and 1 kg of light fuel oil produced in Colombia. "Cradle to gate boundaries"

Parameter	1 kg of maize (US)	1 kg of light fuel oil (Colombia)
Occupation [m² × a]	0,6891	0,0086
Main contributions [%]	— 92 % agricultural land (i.e. maize cultivation) — 4,3 % forest (i.e. wood chips used for energy purposes) — 2,9 % industrial area — 0,27 % infrastructure — 0,25 % transport infrastructure	— 43 % forest (i.e. wood chips used for energy purposes) — 32 % industrial area — 8 % infrastructure (water body artificial) — 5 % mineral extraction (oil) — 4 % transport infrastructure

Parameter	1 kg of maize (US)	1 kg of light fuel oil (Colombia)
	— 0,18 % dump site — 0,18 % mineral extraction site (limestone extraction)	— 4 % dump site — 1 % infrastructure
Transformation [m^2]	1,085	0,0143
Transformation trend	0,005 % of transformed area is passed from natural to anthropic	88 % of transformed area is passed from natural to anthropic
NOTE The data in this table comes from the Ecoinvent database [36] and is used with their permission.		

In comparative life cycle assessment, an accurate check of inventory data should be performed and whenever possible, the average literature data replaced with primary data since, in some circumstances, the land occupation and land transformation associated to the oil extraction and refinement can be one order of magnitude higher [47] compared to that reported in the example of Table A.1. Sensitivity analyses should be performed based on bibliographical data or experts' judgement for sensitive parameters (methane leakage from fracking for instance).

Furthermore, oil extraction activities and transportation can result in oil spills on land and in water causing long-lasting damage to marine and soil ecosystems. In the example of bio-based and fossil feedstocks in Table A.1 it was observed that oil spills are recognized in the inventory (see Table A.2).

Table A.2 — Inventory data on oil released in soil and water associated to the production of 1 kg of maize produced in US (14 % humidity) and 1 kg of light fuel oil produced in Colombia. "Cradle to gate boundaries"

Parameter	Substance	1 kg of maize (US)	1 kg of light fuel oil (Colombia)
Emission to water	Oil, unspecified	0,000 058 kg	0,003 41 kg
Emission to soil		0,000 091 kg	0,003 8 kg
NOTE The data in this table comes from the Ecoinvent database and is used with their permission.			

Nevertheless, the frequencyand the magnitude criteria adopted bydatabaseproviders for accounting the spillsisfundamentalforanappropriatequantificationofthedetrimentaleffectsonlocalwildlife(through direct contact, inhalation and ingestion of toxic chemicals) associated to these incidents.

EXAMPLE According to a recent report by the Center for Western Priorities in 2021 2 418 big and small spills occurred in Colorado, New Mexico and Wyoming combined, which released about 3 500 m^3 of oil in the environment [32]. "Oil, unspecified" is recognized by several LCA impact categories like human toxicity, non-cancer and ecotoxicity, freshwater from the EU Environmental Footprint method [16].

A.5 Examples related to end of life

A.5.1 Comparing compostable and non-compostable materials

One example concerns coffee capsules. Coffee capsules can be made of either aluminium, polypropylene (PP) or compostable materials. The comparison should not be comparing the isolated aluminium vs the isolated PP vs the isolated compostable capsule but should also include the coffee grounds inside the capsule. In both latter cases, first the aluminium and the PP capsules need to be separately collected, shredded, separated from the coffee grains, washed, and finally recycled. If no or limited parts of the capsules are collected and recycled or composted, then this is to be reflected in the study. There is also a need to consider the end-of-life for the separated coffee grounds.

The functional unit for the LCA can be the delivery of 1000 cups of coffee to the final consumer. The scope of the study includes the production of the capsules and coffee, as well as the collection and processing of the wasted capsules looking at the different EOL scenarios.

This example only concerns the option of coffee capsules, just to make the point that the assessment needs to be done including the coffee grounds. Other means of delivering coffee can also be considered which include reusable capsules, and methods which do not require the use of capsules but instead use bulk container packaging. In the reusable capsule, or capsule-free scenario, the impacts of the first production of the capsule and its washing for repeated use, as well as the impact of bulk bag used to deliver the coffee are considered as well.

NOTE EN 16485:2014 contains examples on how to allocate biogenic carbon during recycling.

Even if a product is technically capable of being mechanically composted, for some materials this rarely happens in practice. Instead, the majority of these products are incinerated or landfilled. This needs to be considered in the modelling, based on relevant statistics for waste handling including statistics for composting.

A.5.2 Biodegradable materials

Bio-based plastics such as PLA (polylactide, polylactic acid) are being widely known as biodegradable in industrial composting facilities. But since PLA is a polyester like PET it can also be mechanically and chemically (hydrolysis back to monomer) recycled, so all these options should be considered in the modelling. Also, other bio-based plastics show this combination of EOL properties and other EOL options can be considered. The potential negative impacts of other bio-based plastics on the recycling processes should be assessed as well.

A.5.3 Recycling

Even if a product is technically capable of being mechanically recycled, for some materials this rarely happens in practice. Instead, the majority of these products are downcycled, incinerated or landfilled. This needs to be considered in the modelling, based on relevant statistics for waste handling including statistics for recycling.

A.5.4 Mulch films

Mulch films or other agricultural products are products that are intended to be used and finally released in nature in a controlled way. Soil-biodegradable mulch films are supposed to be ploughed under and biodegrade in a dedicated time frame. Non-biodegradable mulch films are supposed to be collected from the field and recycled. When the mulch films are collected, they are usually contaminated with soil, making mechanical recycling more challenging. Also, the impacts of parts of non-biodegradable films that are blown away or left behind in the soil needs to be taken into account. Also bio-based, soil-biodegradable films can be blown away.

In a comparison of bio-based, soil-biodegradable with fossil-based non-biodegradable mulch films the following topics should be considered during the goal and scope phase:

— Completeness and accuracyof the inventorydata onmechanical recycling ofthe collected mulch film.

— What percentage of the film is removed from the field and what percentage is finally recycled? When mulch films are removed from the field, they are heavily contaminated with soil, which will have an impact on mechanical recycling.

— When mulch films are removed also soil organic carbon is removed together with other nutrients, which can contribute to nutrient depletion.

— During removal of mulch films pieces of mulch films will remain in the soil contributing to "white pollution", generating detrimental effects on the quality of agricultural soil.

— Soil-biodegradable mulch films do not need to be removed from the soil, therefore contributing to reduce the energy consumed in related agricultural operations.

— Parts of mulch films (soil-biodegradable and fossil-based) that are partially disintegrated (not only through microorganisms, but also through mechanical impact or the influence of sunlight) might also be blown away.

NOTE For more details on soil-biodegradable mulch films, see EN 17033.

Inventory data for additional operations that characterize the traditional mulch film product system like the mechanical removal of the film from the soil (agricultural operation), its transport and disposal should be properly taken into consideration. In case of mechanical recycling, the inventory data about mulch film processing should be complete and accurate thus also including the operations for cleaning the film (e.g. water use) and the treatment of process water and other streams.

A.6 Guidance related to using residues and wastes as feedstock

A.6.1 General

Residues and wastes represent a potential source of feedstock which can contribute to a reduced use of virginresources (fossil and/or biogenic) and which canalso increase the circularityof the system. Inboth bio-based and fossil-based systems there is an increasing use of residues and wastes, and in these cases the allocation procedures used should be in line with each other. This clause provides definitions and guidelines for an LCA practitioner carrying out an LCA on products made with residues and wastes.

There is confusion around the terms co-product, residue and waste, and also how the environmental impacts are to be allocated for them when they are used. This is especially relevant in cases where residues and wastes are used as feedstock in the production of a product, i.e. whether the upstream emissions in their production process are to be assigned to them or not.

Main products and certain co-products are primary products and the primary aim of the production process. On the other hand, residues and wastes are secondary products of a process that have inelastic supply with demand, meaning even if the market value of a secondary product increases one would not expect more of it to be produced from that process.

EN ISO 14044 provides a stepwise procedure regarding allocation of co-products in LCA which is also followed in EN 16760:2015, 5.3, where mass or energy allocation is preferred over economic allocation. This applies to the main product and co-products of the unit process. These are different from residues and wastes. As co-products are the primary aim of the production process, they should follow the rules of handling multifunctional processes. For residues and wastes additional guidance is needed and provided below.

A.6.2 Impact assessment

General guidance on how to allocate burdens:

— Process waste streams: no burden from upstream process should be allocated as they have no economic value.

EXAMPLE: Process waste streams are typically left behind on the field in case of agricultural or forestry production systems, incinerated or landfilled.

— Residues: if a residue has no economic value, it should be considered as a process waste stream. However, if the residue has any economic value, it should take a part of the environmental upstream burden, based on an economic allocation procedure.

EXAMPLE: A material that is a secondary product of a process which is inelastic in supply and that has an economic value ratio (based on turnover) of ≤ 5 % with respect to the sum of primary product(s), co-products and other by-products generated from the same production process. No burdens from upstream processes are allocated until the residue has an economic value.

— If, as a consequence of the introduction of new technology or changing market demands a previous waste stream or a residue with low economic value is turned into a residue with a relatively high economicvalue(comparedtothemainproducts)itshouldtakeapartoftheenvironmentalupstream burden.

Since the type of allocation influences the results of the LCA and can lead to wide variations in results, a sensitivity analysis should be carried out.

Examples regarding different feedstocks that can be used in the production of bio-based products:

— Sugar cane – main product (all upstream emissions should be allocated to sugar cane).

— Glycerol – co-product of oil transesterification process (upstream emissions should be allocated between fatty acid product and glycerol).

— Straw – residue if it has value for soil (no upstream emissions should be allocated but should include the burden of (artificial) fertilizer addition due to its diversion for bio-based product production according to the nutritional value) or waste if one needs to dispose of it (no upstream emissions should be allocated but should consider the avoided emissions that would arise from its disposal as credit).

— Used cooking oils – waste collected from the food service industry (no upstream emissions should be allocated).

— Point source CO_2 emissions (of biogenic or fossil origin) – waste (no upstream emissions should be allocated, but the additional burdens from treatment and recovery operations on this source should be accounted).

A.7 Examples of approaches for land use impact assessment related to biodiversity

Three approaches for land use impact assessment are currently available.

a) Ecosystem function based: Specific functions of ecosystems are quantified as services which can build some sort of index that canbe interpreted inview of the conditions for maintained biodiversity. So far, these approaches have been developed for land using processes and plot level only (for example, LANCA method [30] limited to the ecosystem services: erosion resistance, mechanical filtration, physicochemical filtration, formation of new groundwater, and biotic production to inform soil quality index).

b) Ecosystem integrity based: Overall ecosystem integrity is addressed in so called landscape related approaches such as the hemeroby concept which includes the "naturalness" of a landscape in the assessment of land use on plot level. This also is rather a midpoint approach. (This is the hemeroby concept used in [39].)

c) Species richness and vulnerability related: Impacts on species are determined for specific land use types in ecoregions and potential loss rates are quantified as potentially disappeared fraction (PDF). [33]

For end point assessmentthere is damage to ecosystem (canalso be referred as ecosystem quality) which is the area of protection that accounts for impacts on the natural environment. The end point unit used here is PDF (potentially disappeared fraction of species). This metric accounts for a fraction of species richness that can be potentially lost due to an environmental mechanism.

Nevertheless, the methodological approaches might not capture the complexity and variability of biodiversity and its interactions with human activities. For example, a product LCA might not reflect the spatial and temporal distribution of biodiversity along the life cycle: biodiversity is often influenced by natural variability, uncertainty and variability making it hard to account for temporal and spatial dynamics, sensitivity, and adaptability of biodiversity to human pressures.

Biodiversity is influenced by various factors and data on species abundance, ecosystem health and other parameters that can be scarce or difficult to quantify. This lack of data, methodological simplification as well as inconsistency issues associated to the different scale or accuracy can lead to incomplete assessment and inaccurate conclusions making the comparison among systems difficult. For these reasons, the accountability of biodiversity impact in LCA is still under development and the results of comparative studies should be interpreted with care, due to the inherent uncertainties of the integrated assessment and inventory data quality.

A.8 Example of a methodology to evaluate microplastic emission potential

A.8.1 General

This informative annex takes these concepts into consideration and defines a method to evaluate the potential emission of microplastics into the environment (MPEP) from a plastic object. This information can be useful when choosing materials for applications where environmental exposure could lead to the production and emission of microplastics into the environment.

A.8.2 Goal and scope

A.8.2.1 General

A method for characterizing and classifying plastic materials from the point of view of their potential for emitting microparticles and their tendency to persist in the environment in case of leakage is described below. When a polymer product is exposed to the environment, it undergoes environmental degradation leading to the formation of secondary microplastics[5]. As a conservative assumption it is hypothesized that these (secondary) microplastics are dispersed and, therefore, represent an ecological hazard for the biota. The hazard ceases when the microplastics are removed by biodegradation. So, with the same number of microplastics emitted, the ecological hazard is related to the life of the particles. The longer the particles remain in the environment, the more they contribute to the global problem of microplastics. Furthermore, the method is intended to focus on the determination of the potential release of secondary microplastics from a specific polymeric material[6] with standardized dimensions. The proposed method is based on a series of assumptions summarized here:

5 Secondary microplastics represent the results of wear and tear or fragmentation of larger plastic items.
6 The combination of the measure of macroplastic released along product's life cycle with the MPEP of each polymeric material can be used for estimating the overall amount of secondary microplastics released into the biosphere. The quantification of macroplastics and microplastics from tyre abrasion (transportation phase) released in the environment along the life cycle of a product or a service can be estimated by applying the guidelines developed within the Plastic Leak Project (PLP) [45].

— The number of microplastics released from a standard sample (described below) is considered constant.

— The permanence of the released microplastics (MP) is controlled by the biodegradation rate.

— The life of microplastics is the time necessary to obtain their complete biodegradation (t_d). Thus, if the time to complete biodegradation (t_d) is 1 year, each MP will exist for 1 year, regardless of when it was released. An MP released from the standard polymer article at time zero will cease to exist after one year. Similarly, an MP issued by the same article after 10 years, for example, will cease to exist in the 11th year, i.e. again after a year.

— It is considered that the overall contribution in MP of a polymeric material depends not only on the total number of MP that can be released but also on the life span of each microplastic.

To define the parameter: microplastic emission potential [35] (MPEP) a standard sample is considered: 10 cm × 10 cm × 100 µm of a defined polymer, which can be a traditional plastic (PE, PP, PET, etc.) or a biodegradable and compostable plastic in accordance with international standards (such as EN 13432, ISO 17088). This standard sample, exposed to a natural environment, will undergo a degradation process and consequent fragmentation into microplastics which will biodegrade over time with different speeds. Considering that 80 % of the release of plastics into the environment takes place on land [42, 43], i.e. the soil is the first environment to be affected.

A.8.2.2 Measurement of the time required for the complete biodegradation of microplastics

The biodegradation tests can be conducted using, for example, the test methodology described in EN ISO 17556, using pure microcrystalline cellulose for column chromatography purposes as a positive reference. The biodegradation test is performed on a grounded material obtained with methods not causing thermodegradation phenomena (e.g. those using liquid nitrogen) so as to form microplastics of standard dimensions. The final grain size of the test material and the reference material should be similar preferably between 125 µm and 250 µm.

NOTE EN ISO 17556 is a test method to measure biodegradability of plastics in soil in mesophilic condition. Soil is generally the first environment that can receive microplastic. In principle the test methods developed for plastics listed could be suitable to characterize materials biodegradability however the referring to EN ISO 17556 provides consistence between data. It is also a test method that can be prolonged over a relatively long period of time in order to collect significative data also for materials which are biodegrading at lower rates.

For the current method, the degradation time t_d is expressed in years and it corresponds to the time necessary to obtain complete biodegradation, that is a mineralization of at least 90 %, absolute or relative, compared to the reference material.

EXAMPLE If the microplastics of a certain material undergo complete biodegradation in the six months of testing in the constituent material, it will have a t_d of 0,5 (6 months/12 months) while a sample that reaches it in 36 months will have a t_d of 3 years.

If it is impossible or very difficult to experimentally calculate the t_d due to a very low rate of biodegradation (a situation that occurs with conventional non-biodegradable polymers), then it can be estimated from data available in the literature such as those present in references [43], [24] and [25] which corresponds, for PE, to about 548 years.

A.8.3 Life cycle inventory

The method described in this standard aims to characterize solid materials in terms of their potential to contribute to the MPs released in environment, by producing a score, called MPEP (microplastic emission potential). It is based on the following assumptions:

a) The analysis starts from an article of standard dimensions made with the polymer of interest.

b) Its dimensions are 10 cm × 10 cm × 100 µm, with a volume of 1 cm^3.

c) Its density is fixed at 1 g/cm^3.

d) The standard sample undergoes degradation in the environment.

e) The degradation causes a progressive fragmentation of the sample with loss of volume.

f) All the volume lost by the conventional object gives rise to "standard size microplastics", i.e. cubes with a side of 100 µm.

g) MPs persist in the environment as particles until they degrade completely to CO_2 and biomass. The time required to achieve complete biodegradation is t_d.

h) During this period, which goes from the moment MPs are generated by fragmentation to the moment they are completely biodegraded, the particles are counted as MPs.

The time required for biodegradation (t_d expressed in years) expresses the permanence of microplastics in the environment itself.

The total fragmentation of the considered sample will produce a number of microplastics in cubic form with a side of 100 µm, as shown in Formula A.3:

$$N_{mp} = V_i / V \qquad \text{(A.3)}$$

where

N_{mp}	is number of microplastics;
V_i	is volume of the sample, i.e. 1 cm^3;
V_{mp}	is volume of each individual microplastic, i.e. 1×10^{-6} cm^3.

The standard number of microplastics (N_{mp}) for all types of polymers will be 1×10^6. The microplastic emission potential (MPEP) is calculated as shown in Formula A.4:

$$MPEP = N_{mp} \times t_d \qquad \text{(A.4)}$$

where

$MPEP$	is microplastic emission potential;
N_{mp}	is number of microplastics;
t_d	is time required for biodegradation expressed in years.

For example, a plastic material that reaches complete biodegradation in 1,5 years:

$MPEP = 10^6 \times 1{,}5 = 1\,500\,000$

The MPEP only determines the overall level of potential emission and permanence of MPs by a polymeric item.

A.8.4 Impact assessment

In order to simplify the MPEP index interpretation, it is possible to use a relative index RMPEP, corresponding to the ratio between the MPEP of the plastic material and that of cellulose, a natural polymer which is rapidly biodegradable, and whose MPEP is assumed to be equal to 300 000. This value considers a degradation time t_d of 0,3 years.

NOTE In experimental practice the t_d of cellulose can show values higher or lower than 0,3. However, for the purposes of this method, for reasons of comparison, the value of 0,3 is taken into consideration. The t_d 0,3 relating to cellulose, i.e. a degradation time of about 4 months (0,3 years) can also be detected by the round robin test described in EN ISO 17556:2019, Annex G.

Therefore, MPEP of a plastic material whose microplastics reach complete biodegradation in 1,5 years (see previous example) will be equal to:

RMPEP = 1 500 000/300 000 = 5

Similarly, the RMPEP of the PE will be equal to 1827.

A.8.5 Interpretation

The quantification of the microplastic emission potential (MPEP) can help in qualifying polymeric materials and assess their magnitude to cause a potential ecological and human hazard, whose quantification is an important result to aim for (MariLCA [44]) but still under development. Within LCA studies MPEP or RMPEP can therefore provide a preliminary indication of the microplastic pollution potential. Furthermore, the combination of the measure of the microplastic and macroplastic (e.g. plastic pellet leaked in the environment during operations) released along a product's life cycle with the MPEP (specific to each polymer) can be used for estimating the effective amount of microplastics released into the biosphere associated to a plastic product (e.g. plastic packaging), especially important for product eco-design purposes.

The assessment of the microplastic emission potential can help in selecting materials for their expected lower ecological hazard, nevertheless, a full hazard characterization is necessary in order to carry out a physical and chemical-physical risk assessment of MPs that can support in the interpretation when comparing bio-based and fossil-based product systems.

Due to the simplifications that characterize the proposed MPEP metric, it should be considered as additional information which will help to qualify the product's potential ecological hazard associated to the production of secondary microplastics (i.e. sooner or later all polymeric materials release secondary microplastics into the environment). The higher MPEP, the higher the expected ecological hazard.

A.9 Examples of indirect effects

Examples of indirect effects are:

— Indirect effects of changes in land use (iLUC), e.g. if land use on a particular piece of land changes from food production to biofuel production, land use change might occur elsewhere to meet the demand for food. This land use change elsewhere is indirect land use change.

— As a result of an increased production of a bio-based product, more agricultural raw materials are required. These could be compensated by taking more land into production (indirect land use change, iLUC) or from an increased production on the same land. In the latter case no iLUC takes place.

Whenmore fossil-based products are used the CO_2 emissions rise causing climate effects which inits turn affects the plant zones, and this can lead to iLUC as well.

— Indirect effects by road construction and accessing oil fields.

— Indirect effects by military and security operations of oil fields and oil supply routes.

— Indirect effects of changes in oil production and subsequent availability of refinery co-products.

Annex B
(informative)

Overview of key aspects of approaches for biogenic carbon accounting adopted in relevant standards and guidelines

The Tables B.1, B.2 and B.3 below give an overview of how different standards have handled different carbon-related issues. The “shalls” included in this annex refer to requirements in those standards. Those requirements do not apply for this document unless they are included elsewhere in this document.

Table B.1 — Overview of key aspects of approaches for biogenic carbon accounting adopted in relevant standards and guidelines

	EN ISO 14067: 2018	EN 16760: 2015	PEF [16]	BSI/PAS 2050 [12]	GHG Protocol [40]	ILCD Handbook [14]	ISO 21930: 2017 EN 15804 [3]	ISO 22526-4: 2023	JRC report [15]
Biogenic carbon removals and emissions to be included in the inventory/ modelling	Yes	Yes	Yes[a]	Yes, except for food and feed	Yes	Yes	Yes	Yes	Yes
Impact assessment of biogenic carbon emissions and removals	CFs = −1/+1	CFs may be either set to −1/+1 or 0/0	CFs = 0/0[b]	n.s. (−1/+1)[c]	CFs = −1/+1	CFs = −1/+1	CFs = −1/+1	CFs = −1/+1	CFs = 0 /0
Biogenic carbon removals and emissions to be reported (or inventoried) separately	Yes	Yes	Yes[d]	n.s.	Yes	Yes	Yes	Yes	Yes
Biogenic carbon content in intermediate products to be separately reported	Yes	No requirement	Yes	No requirement	Yes	No requirement	No requirement	Yes	Yes
Delayed emissions due to temporary carbon storage included in the assessment	No, can be reported separately, a minimum storage time of 10 years is considered.	No, should be taken into account where relevant but reported separately.	No	No, can be reported separately together with the main results.	No, can be reported separately.	No, can be taken into account if directly required in the goal of the study.	No, ISO 21930 state it can be reported separately.	No	No

	EN ISO 14067: 2018	EN 16760: 2015	PEF [16]	BSI/PAS 2050 [12]	GHG Protocol [40]	ILCD Handbook [14]	ISO 21930: 2017 EN 15804 [3]	ISO 22526-4: 2023	JRC report [15]
Calculation method for including the effect of delayed emissions specified	No	Yes, the calculation method specified in the ILCD Handbook may be followed.	No	Yes	No	Yes	No	No	No
"Permanent" carbon storage included in the assessment	yes[e]	Yes, can be reported separately.	No	Yes, carbon storage of > 100 years is considered permanent.	Yes, a minimum time period of 100 years considered.[f]	Yes, inventoried separately using 100-year time-frame; emissions occurring after 100 000 years not accounted.	No	No	No
Nomenclature and structure for Impact category indicators and sub-indicators	See Table B.2.	-	-	-	-	-	-	-	-
Characterization models referred to	See Table B.3.	-	-	-	-	-	-	-	-

NOTE n.s. = not specified

	EN ISO 14067: 2018	EN 16760: 2015	PEF [16]	BSI/PAS 2050 [12]	GHG Protocol [40]	ILCD Handbook [14]	ISO 21930: 2017 EN 15804 [3]	ISO 22526-4: 2023	JRC report [15]

[a] Unless a simplified modelling approach (where only biogenic CH_4 emissions are modelled) is selected in a specific PEFCR.

[b] Under review.

[c] Not explicitly reported in the standard, but it can be inferred from provisions related to other relevant aspects.

[d] The provision in the PEF method refers to the modelling, not to the reporting. Biogenic carbon emissions and removals shall be modelled separately in the inventory, but not reported (separately) in the PEF results. This applies unless a simplified modelling approach is selected in a specific PEFCR.

[e] The standard does not report any specific time horizon (or assessment period) after which carbon removed from the atmosphere (e.g. during biomass growth) shall be considered as no longer released, and hence as "permanently" stored.

[f] Companies shall report the time period of the inventory. Companies shall report the amount of carbon contained in the product or its components that is not released to the atmosphere during waste treatment and therefore is considered stored.

Table B.2 — Overview of nomenclature and structure for impact category indicators and sub-indicators adopted in relevant standards and guidelines

	Impact indicator name	Sub-indicator	Comment
EN ISO 14067:2018	CFP (Carbon footprint of products)	net fossil GHG emission and removal	shall be included
		biogenic GHG emissions	
		biogenic GHG removal	
		emissions from dLUC and change in the management of land	
		removal from dLUC and change in the management of land	
		aircraft emissions	
		emissions from LU excluding change in the management of land	
		GHG emissions other than specified	
		removal from LU excluding change in the management of land	should be included
		biogenic carbon in the product	shall be documented separately
		iLUC emissions	should be considered separately
		iLUC removals	
EN 16760:2015	n.a.	n.a.	No specific indicator names listed but requires that all biogenic and non-biogenic carbon emissions and removals should be considered. Where temporal accounting of GHG emissions is relevant, it should be taken into account but reported separately. Standard requires that reporting guidelines provided in EN ISO 14040:2006, Clause 6 and EN ISO 14044:2006, Clause 5 shall be followed.

	Impact indicator name	Sub-indicator	Comment
PEF [16]	Climate change, total	climate change, fossil	-
		climate change, biogenic	
		climate change – land use and land use change	
BSI/PAS 2050 [12]	GHG Emissions	GHG emissions	Both emissions to the atmosphere and removals from the atmosphere shall be accounted for. The assessment shall include specified gases arising from both fossil and biogenic sources (with some exceptions for food and feed). The detailed list of specified gases includes, amongst others, CO_2, CH_4, N_2O, as well as CFCs, HFCs, PFCs, SF_6 and NF_3.
		GHG removals	
GHG Protocol [40]	GHG emissions	net fossil GHG emission and removal	including fossil CO_2 and all CH_4 and N_2O (excluding biogenic CO_2)
ILCD Handbook [14]	Climate change	n.a.	Eleven specific sub-criteria have been developed for Evaluation of this impact category within the main criteria "Environmental relevance" and "Scientific robustness":
ISO 21930:2017 **EN 15804 [3]**	Global warming potential	GWP – fossil	a GWP – total is also mentioned
		GWP – biogenic	
		GWP – land use and land use change (LULUC)	

	Impact indicator name	Sub-indicator	Comment
ISO 22526-4: 2023	CFP (Carbon footprint of products)	Same as for EN ISO 14067.	Includes the requirement about that carbon footprint studies shall be in accordance with ISO 14067.
JRC report [15]	Climate Change, total	Climate Change – fossil; Climate Change – biogenic; and Climate Change – land use and land use change	The sub-indicators are further described in section 4.4.15. The microplastic of each sub-indicator shall be reported separately if it is larger than 5 % of the total Climate Change score.

Table B.3 — Overview of versions of the IPCC reports referred to in the different relevant standards and guidelines, status April 2022

	Impact indicator name	Impact category indicator	Unit	Characterization model	Comment	GWP 100 methane	GWP 100 N_2O
EN ISO 14067: 2018	CFP (Carbon footprint of products)	GWP 100	kg CO_2e	100-year GWP as given by IPCC (with carbon feedbacks)	Latest IPCC AR report with carbon feedbacks = AR6 draft IPCC 2021	CH_4-fossil 29,8 (±11) CH_4-non fossil 27,2 (±11)	273 (±130)
EN 16760: 2015	n.a.	n.a.	n.a.	n.a.	No details specified but standard requires that reporting guidelines provided in EN ISO 14040:2006, Clause 6 and EN ISO 14044:2006, Clause 5 shall be followed.	n.a.	n.a.
PEF [16]	Climate change, total	GWP 100	kg CO_2e	Baseline model of 100 years of the IPCC (based on IPCC 2013)	Values provided at PEF homepage April 2022	Methane (fossil) 36,8 Methane (biogenic) 34	298
BSI/PAS 2050 [12]	GHG emissions	GWP 100	kg CO_2e	GHG emissions and removals shall be converted into CO_2e using the latest IPCC 100-year global warming potential (GWP) coefficients.			
GHG Protocol [40]	GHG emissions	GWP 100	kg CO_2e	Companies may either use the IPCC GWP values agreed to by UNFCCC United Nations Framework Convention on Climate Change) or the most recent GWP values published by the IPCC.			
ILCD Handbook [14]	Climate change	Radiative forcing as Global Warming Potential (GWP100)	kg CO_2e	Baseline model of 100 years of the IPCC		n.a.	n.a.

	Impact indicator name	Impact category indicator	Unit	Characterization model	Comment	GWP 100 methane	GWP 100 N_2O
ISO 21930: 2017 **EN 15804 [3]**	Global warming potential	GWP 100	kg CO_2e	EN 15804, Version Aug 2021 (Original reference IPCC 2013)	Values provided at EPD homepage April 2022	Methane (fossil) 36,8 Methane (biogenic) 36,8	298
ISO 22526-4: 2023	CFP (Carbon footprint of Products)	GWP-100	kg CO_2e	100-year GWP as given by IPCC (with carbon feedbacks)		CH_4-fossil 29,8 (+-11), CH_4-non fossil 27,2 (+-11)	273 (+-130)
JRC report [15]	Climate change	Radiative forcing as Global Warming Potential (GWP100)	kg CO_2e	Baseline model of the IPCC over a 100 year time horizon (IPCC, 2013)			

EN ISO 14040/14044:2006 include no specific provisions to address biogenic carbon accounting.

EN ISO 14067:2018 (Carbon footprint of products): GHG emissions and removals arising from fossil and biogenic carbon sources and sinks shall be included in the carbon footprint and shall be documented separately. This standard requires that all emissions and removals shall be calculated as if released or removed at the beginningof the assessment period,without taking intoaccount anyeffect of delayed GHG emissions and removals. No time horizon is specified after which carbon in products shall be considered as "permanently" stored. A minimum storage time of 10 years is required to account for the effects of temporary storage (although PCRs may define alternative values). If any carbon storage in products is calculated, it shall be documented separately. Carbon storage in products may also be provided for information when performing cradle-to-gate studies when this information is relevant for the remaining value chain. In Annex I of the recent EU Taxonomy Climate Delegated Act, technical screening criteria for plastics derived from renewable feedstock, i.e. biomass, industrial bio-waste or municipal bio-waste, state life cycle GHG emissions are calculated using EN ISO 14067.

EN 16760:2015(Bio-based products –LifeCycle Assessment):Similar toEN ISO 14067, EN 16760states that GHG emissions and removals arising from fossil and biogenic carbon sources and sinks shall be included and listed separately in the inventory. The standard states that a simplified approach may be used to determine the net quantity of atmospheric carbon dioxide fixed in a product using stoichiometry or the biogenic carbon content. Where temporal accounting of GHG emissions is relevant, it should be taken into account but reported separately. In Annex A examples of fossil and biogenic carbon flows accounting and communication are provided. An example of "temporal accounting" is reported in A.3 where an approach based on "discounting" of emissions over a 100-year time horizon is reported, based on the method described in ILCD Handbook. No minimum storage time is defined. It is also considered that when greenhouse gasses are removed over more than 100 years, these removals shall be calculated as if they were "permanently" stored.

PEF method (Product Environmental Footprint method) [16]: Biogenic carbon uptakes and emissions shall be inventoried separately for each elementary flow. The PEF method considers characterization factors for biogenic CO_2 uptakes and emissions are set to zero. This method has also been followed in the JRC Plastics LCA study for plastics [15]. For intermediate products, the biogenic carbon content at factory gate (physical content and allocated content) shall be reported as 'additional technical information'. Credits associated with temporary and permanent carbon storage and/or delayed emissions shall not be

considered in the calculation of the Climate Change impact indicator. This means that all emissions shall be counted as emitted at the same point in time and there is no discounting of emissions.

GHG Protocol [40] (Product life cycle accounting and reporting): Biogenic emissions and removals are separately reported. Temporary storage is not allowed, weighting factors for delayed emissions shall not be used for calculating the GWP. Companies shall report the amount of carbon contained in the product that is not released to the atmosphere during waste treatment, if applicable (permanent storage). The time period should be based on scientific evidence to the extent possible, and sector guidance or product rules may be a source of this information when available. If known science, sector guidance, or product rules do not exist, companies should assume a minimum time period of 100 years including the end-of-life stage. For cradle-to-gate inventories, companies shall report the amount of carbon contained in the intermediate product.

BSI/PAS 2050 [12] (Specifications for Life cycle GHG emissions): It is stated that removed carbon, not emitted to the atmosphere within the 100-year assessment period, shall be treated as stored carbon. Emissions that occur within the 100-year period may be taken into account using weighting factors. The methodology of this calculation is described in the guidance and already taking effect of the delay in emissions into account from the second year after production. For short lived products like food and feed carbon neutrality is considered.

ILCD Handbook [14]: The ILCD handbook require both the uptake of CO_2 from the atmosphere and the release of both fossil and biogenic CO_2 are assigned characterization factors for the impact assessment. ILCD distinguishes between carbon that is released within a 100-year period and carbon that is released more than 100 years after the bio-based product was produced. For carbon that is released within 100 years a benefit/credit can be calculated according to the number of years of carbon storage where ILCD handbook provides methodology for its calculation. This temporary carbon storage is excluded from assessment and separately calculated and reported. Emissions and other elementary flows that occur beyond the 100 years shall be inventoried separately (long-term). Long term emissions shall be accounted for by inventorying no emissions at all, if the respective storage form can guarantee that it is not emitted to the atmosphere for at least 100 000 years.

Annex C
(informative)

Models for land use

In Table C.1, land use models that do not have characterization factors associated to land use flows are not takenintoaccount. The methods listed inTable C.1 are not anexhaustivelist.Otheravailablemethods and emerging methods can also be applied where appropriate.

Table C.1 — Models for land use

Model	Main indicators	CFs associated to the land use flows	Geographic coverage	Spatial resolution
Brandão and Milà I Canals (2013) [31]	- Soil Organic Carbon (SOC) – as indicator of Biotic Production Potential (BPP)	Yes	Global	World and climate regions
LANCA-- Land Use Indicator Value Calculation in Life Cycle Assessment [28], [30]	- Erosion resistance - Mechanical filtration - Physicochemical filtration - Groundwater replenishment - Biotic production	Yes	Global	World, country, and local (site-specific application)
Saad et al. (2013) [45]	- Erosion resistance - Mechanical filtration - Physicochemical filtration - Groundwater recharge	Yes	Global	World and biogeographical regions
Alvarenga et al. (2013) [26]	- Exergy of natural land (biomass extraction-based) - Exergy of human-made land (potential NPP-based)	Yes [a]	Global	World and country
Alvarenga et al. (2015) [27]	- Human Appropriation of Net Primary Production (HANPP)	Yes	Global	World and country

[a] Limited CFs availability.

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