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Plastics — Carbon and environmental footprint of biobased plastics —

Part 4: Environmental (total) footprint (Life cycle assessment)

Plastiques — Empreinte carbone et environnementale des plastiques biosourcés —

Partie 4: Empreinte environnementale (totale) (Analyse de cycle de vie)

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Foreword

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This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 14, *Environmental aspects*.

A list of all parts in the ISO 22526 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Increased use of biomass resources for manufacturing plastic products can be effective in reducing global warming and the depletion of fossil resources.

Current plastic products are composed of biobased synthetic polymers, fossil-based synthetic polymers, natural polymers and additives that can include biobased materials.

Biobased plastics refer to plastics that contain materials wholly or partly of biogenic origin.

Plastics — Carbon and environmental footprint of biobased plastics —

Part 4: Environmental (total) footprint (Life cycle assessment)

1 Scope

This document provides life cycle assessment (LCA) requirements and guidance to assess impacts over the life cycle of biobased plastic products, materials and polymer resins, which are partly or wholly based on biobased constituents.

The applications of LCA as such are outside the scope of this document. Clarifications, considerations, practices, simplifications and options for the different applications, are also beyond the scope of this document.

In addition, this document can be applied in studies that do not cover the whole life cycle, with justification, for example in the case of business-to-business information, such as cradle-to-gate studies, gate-to-gate studies, and specific parts of the life cycle (e.g. waste management, components of a product). For these studies, most requirements of this document are applicable (e.g. data quality, collection and calculation as well as allocation and critical review), but not all the requirements for the system boundary.

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.

ISO 472, *Plastics — Vocabulary*

ISO 14025, *Environmental labels and declarations — Type III environmental declarations — Principles and procedures*

ISO 14040:2006, *Environmental management — Life cycle assessment — Principles and framework*

ISO 14044:2006, *Environmental management — Life cycle assessment — Requirements and guidelines*

ISO/TR 21960, *Plastics — Environmental aspects — State of knowledge and methodologies*

EN 16575, *Bio-based products — Vocabulary*

EN 16760, *Bio-based products — Life cycle assessment*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 472, ISO 14040, ISO 14044, EN 16575, EN 16760 and ISO/TR 21960 apply.

ISO and IEC maintain terminological 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/

4 Methodology for LCA of biobased products

4.1 General description of an LCA

The general description of life cycle assessment is defined in ISO 14040:2006, Clause 4.

4.2 General aspects of LCA for biobased plastic products

The LCA of a biobased plastic product shall cover the whole product, not only the biobased part; see Figure 1. However, the focus of this document is on how to handle the specificities of the biobased part of the product.

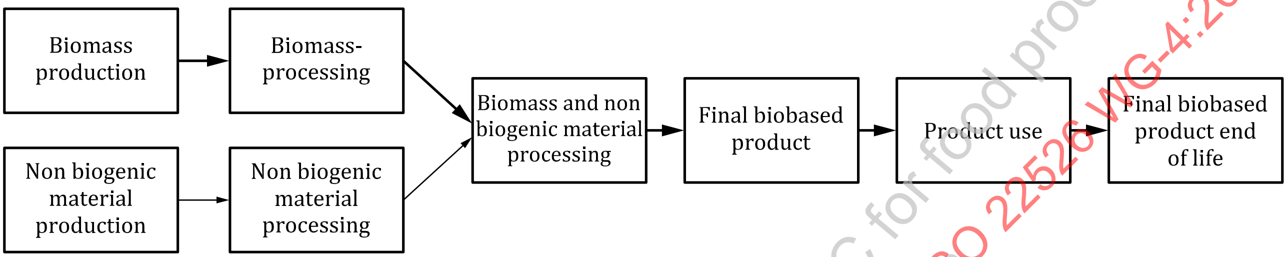

Figure 1 — Example of a product system of a biobased plastic product which includes biomass as well as non-biogenic material feedstocks

NOTE 1 The boxes linked with bold arrows in Figure 1 represent the flows of biobased products (partly or fully derived from biomass) that can be raw materials, intermediary products and final product.

NOTE 2 For simplification purposes, transportation steps have not been reported in Figure 1, but transportation can occur within or between any of the unit processes.

This document provides requirements and guidelines for biobased products: see 4.3, Clause 5, Clause 6 and Clause 7.

An LCA for a biobased product shall include the four phases of LCA. LCA requirements and guidelines are provided in ISO 14044:2006, 4.2, 4.3, 4.4 and 4.5.

This document provides further guidance on the following, which can be important for biobased plastic products, due to their biomass origin:

— geographical (see 5.2.2) and temporal scope (see 5.2.3) to be representative for the biomass acquisition phase considering agricultural, forest and aquaculture specificities;

— allocation procedures (see 5.3) as the production stages typically generates co-products;

— consideration for resource elementary flows (see 5.4.1);

— data collection and modelling for land use (see 5.4.2), water use (see 5.4.3), and fossil and biogenic carbon flows (see 5.5);

— modelling of agriculture and aquaculture systems (see 5.6) and

— inventory and modelling requirements for biobased plastic products end-of-life (see 5.6.4).

The ISO 22526 series focuses on biobased products for industrial application; food, feed and energy are excluded from the scope. However, the guidelines and requirements for LCA provided in this document can be applied to any product derived from biomass, irrespective of the application.

4.3 Goal and scope of the LCA study

4.3.1 Goal of the LCA study

When defining the goal of the LCA study, the requirements of ISO 14040:2006, 5.2.1 and ISO 14044:2006, 4.2.2 and 4.2.3 shall apply.

There is no single solution as to how LCA can be best applied, it depends on the goal of the LCA and on each organization size and culture, its products, the strategy, the internal systems, tools and procedures and the external drivers.

In defining the goal of an LCA, the following items shall be clearly stated:

— the intended application of the study;

— the reasons for carrying out the study;

— the intended audience, i.e. to whom the results of the study are intended to be communicated; and

— whether the results are intended to be used in comparative assertions intended to be disclosed to the public.

4.3.2 Scope of the LCA study

4.3.2.1 General

The scope should be sufficiently well-defined to ensure that the breadth, depth and detail of the study are compatible and sufficient to address the stated goal.

In addition to the definition of the scope of the LCA study in ISO 14044:2006, 4.2.3, the limitations, assumptions and methods to assess issues specific to biobased products should be explained (e.g. assumptions for use stage, for end-of-life stage, carbon storage).

In some cases, the goal and scope of the study may be revised due to unforeseen limitations, constraints or as a result of additional information. Such modifications, together with their justification, should be documented.

It shall be determined which impact categories, category indicators and characterization models are included within the LCA study. The selection of impact categories, category indicators and characterization models used in the LCIA methodology shall be consistent with the goal of the study and considered as described in ISO 14044:2006, 4.4.2.2.

4.3.2.2 Function and functional unit

In defining the functional unit, the requirements of ISO 14040:2006, 5.2.2 and ISO 14044:2006, 4.2.3.2 shall apply.

The scope of an LCA shall clearly specify the function (performance characteristics) of the product system being studied. The functional unit shall be consistent with the goal and scope of the study. One of the primary purposes of a functional unit is to provide a reference to which the input and output data are related. This reference is necessary to ensure comparability of LCA results, in particular when different systems are being assessed to enable comparison on a common basis. Therefore, the functional unit shall be clearly defined and measurable.

An appropriate reference flow shall be determined in relation to the functional unit. The quantitative input and output data collected in support of the analysis shall be calculated in relation to this flow. For biobased products which are intermediates or which can serve several functions or services, it is recommended to use a reference flow such as weight or volume (e.g. 1 kg of product), and to provide information whether it refers to dry matter weight, gross weight, etc.

EXAMPLE In the function of drying hands, both a paper towel and an air-dryer system are studied. The selected functional unit can be expressed in terms of the identical number of pairs of hands dried for both systems. For each system, it is possible to determine the reference flow, e.g. the average mass of paper or the average volume of hot air required for one pair of hand-dry, respectively. For both systems, it is possible to compile an inventory of inputs and outputs on the basis of the reference flows. At its simplest level, in the case of paper towel, this is related to the paper consumed. In the case of the air-dryer, this is related to the mass of hot air needed to dry the hands (copied from ISO 14040:2006, 5.2.2).

4.3.2.3 System boundary

In defining the system boundary, the requirements of ISO 14040:2006, 5.2.3 and ISO 14044:2006, 4.2.3.3 shall apply.

The system boundary shall be explained clearly and in an unambiguous way, preferably in a flow chart figure. The exclusion of any life cycle stage shall be documented and explained.

LCA technique with proper justification may be applied in studies that are not LCA or LCI studies. Examples are:

— cradle-to-gate studies;

— gate-to-gate studies; and

— specific parts of the life cycle (e.g. waste management, components of a product).

4.3.2.4 Cut-off criteria

When using cut-off criteria to decide on inclusion of inputs and outputs, the requirements of ISO 14044:2006, 4.2.3.3.3 shall apply.

The choice of elements of the physical system to be modelled depends on the goal and scope definition of the study, its intended application and audience, the assumptions made, data and cost constraints, and cut-off criteria. The models used should be described and the assumptions underlying those choices should be identified. The cut-off criteria used within a study should be clearly understood and defined within the goal and scope definition phase.

In principle, all elementary and technosphere flows should be accounted for. If not, mass, energy and environmental significance should be used to determine cut-off criteria. The final report shall include an estimation of completeness, based on:

— Mass cut-off (in % of total product mass): best estimation of the mass of all non-accounted components of the product.

— Energy cut-off (in % of total energy consumption): best estimation of all energy consumption of non-accounted mass inputs.

— Environmental significance: decisions on cut-off criteria should be based on best knowledge of environmental significance. Such information may, for example, be sought on safety data sheets for toxicological and ecotoxicological effects of a product where substance classification can guide on possible cut-offs regarding such categories. For assessment of other relevant environmental impacts also other sources of information should be looked for, such as emission declaration, approval documentation, etc. Inputs such as transport of staff, or consumer transport may be excluded as where it is established that they are insignificant.

Such simplifications shall be explicitly stated in the study report along with any supporting documentation showing these calculations, specifying the names of any flows which have not been taken into consideration.

4.3.2.5 LCIA methodology and types of impacts

The choices of which impact categories, category indicators and characterization models are selected within the LCA study shall be explained.

4.3.2.6 Data quality

Data quality requirements shall be specified to enable the goal and scope of the LCA to be met and should address what is listed in ISO 14044:2006, 4.2.3.6.2 and 4.2.3.6.3.

Site-specific and primary data should be used when appropriate and in line with the goal and scope of the study.

The selection of level of geographical detail should be consistent with the goal and intended use of the LCA and be justified in view of the availability and quality of data.

4.3.2.7 Comparisons between systems

As this document provides additional guidance and requirements for biobased products, 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 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. Based on this information a well-reasoned assessment shall be included why the study is valid and can be performed or why a comparison is very problematic or even scientifically not allowed. In the latter case, such a study should not be terminated, but still should be published to educate about the limits of LCA. 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.

A life cycle impact assessment is an integral part of any LCA study, but especially for studies intended to be used in comparative assertions and be disclosed to the public, this impact assessment part shall be performed with utmost care.

If comparative assertions are intended to be disclosed to the public, additional requirements as set in ISO 14044 apply.

5 Life cycle inventory (LCI)

5.1 General

Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system.

The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures so that the goals of the study will still be met. Sometimes, issues can be identified that require revisions to the goal or scope of the study.

The qualitative and quantitative data for inclusion in the inventory shall be collected for each unit process that is included within the system boundary. The collected data, whether measured, calculated or estimated, are utilized to quantify the inputs and outputs of a unit process. All individual unit processes should be taken up in a process flow diagram representing the studied system and so also identifying the system boundary.

When data have been collected from public sources, the source shall be referenced. For those data that can be significant for the conclusions of the study, details about the relevant data collection process, the time when data have been collected, and further information about data quality indicators shall be referenced.

If life cycle inventory data do not meet the data quality requirements, as given in 4.3.2.6, this shall be reported.

To decrease the risk of misunderstandings (e.g. resulting in double counting when validating or reusing the data collected), a description of each unit process shall be recorded.

Since data collection may span several reporting locations and published references, measures should be taken to reach uniform and consistent understanding of the product systems to be modelled.

5.2 Sources of data

5.2.1 General

Sources of inventory data should be specified and transparent.

Responsible sourcing and sustainable management practices can be found in the production of biobased raw materials. Certification schemes usually address a broad array of management and performance aspects that can be used directly in determining elementary flows and in informing impact assessment and interpretation.

EXAMPLE Managing conformity with standards covering fertiliser application can be linked directly to levels of fertiliser run-off and therefore elementary flow determination.

If biomass has been produced in conformance with a relevant standard this shall be taken into account in determining elementary flows and in impact assessment and interpretation.

The most representative data should be used and the quality of data shall always be examined in order to guarantee that they are adequate for the purpose of the study, and that they conform with the data quality requirements of the study.

5.2.2 Geographical data

Average data should be collected and assessed across a representative geographical area where the specific biomass has been produced. The data and scales used should be clearly specified in the study in order to ensure optimal transparency. Mean values by region can be used only for part of agricultural data (contributions from fertilisers, yields, etc.), since other variables cannot yet be regionalised due to the lack of a recognized model (e.g. N_2O emissions).

5.2.3 Temporal data

Time period is an important issue in LCA, as emissions to air, water and soil are subject to variation over the management cycle of the system. The LCI should cover the relevant period in the life cycle of the product.

For industrials processes and systems, the inventory may cover the cycle of productions, e.g. seasonal production, start-up, maintenance, and temporary process shutdown.

For biomass production the collection of data and modelling should consider the management regime and cropping or harvesting and crop rotation [including the positioning of the crop in the rotation], e.g. the effect of inter- and intra-annual variation and when possible use values representing the selected period.

Ideally, average biomass production data should be collected over a period of at least three recent consecutive years.

5.3 Allocation procedure

The inputs and outputs shall be allocated to the different products according to clearly stated procedures that shall be documented and explained together with the allocation procedure.

The sum of the allocated inputs and outputs of a unit process shall be equal to the inputs and outputs of the unit process before allocation. This can be demonstrated by including a mass balance over each individual unit process.

In line with ISO 14044, the study shall identify the processes shared with other product systems and deal with them according to the following procedure.

Step 1: Wherever possible, allocation should be avoided by:

1) dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes; or

2) expanding the product system to include the additional functions related to the co-products, taking into account the requirements of ISO 14044:2006, 4.2.3.3.

NOTE 1 System expansion means "expanding the product system to include additional functions", so all additional functions are modelled and calculated and there are multiple benefits; nothing is subtracted.

Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.

NOTE 2 Allocation based on the underlying physical relationship do not include, for example, simple mass or energy allocation unless this reflects by an independent change in mass or energy of each product.

Step 3: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.

For economic allocation, an average economic value on a relevant time period should be used and the geographical scope of the study should be considered in order to limit high variation of results.

For biobased products, the biogenic carbon content can be of key importance to determine greenhouse gas emissions. To track biogenic carbon in a value chain, allocation based on carbon content can be used. When allocating based on other relationships the modelled biogenic carbon flows might not reflect the actual physical content and flows.

Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach.

Annex A provides an example of allocation and a sensitivity analysis.

5.4 LCI — Collecting data and modelling

5.4.1 Considerations for resource use

The inventory of natural resources (such as fossils and oils) in an LCA is of primary importance because when moving from an LCI to LCIA environmental, resource depletion impacts will be associated to the use of these natural resources.

The definition of natural resource versus raw material is decisive for biomass. Natural resources enter the system as elementary flows, while raw materials are intermediate flows within the system. Biomass shall be inventoried as an intermediate flow because it comes from a harvesting process. It can be inventoried as an elementary flow where it enters the system without prior human intervention.

In LCI modelling for biobased products, it is necessary to further distinguish material use from the use of energy.

Resources can be consumed to provide the energy needed to produce the product under consideration.

Resources can also be used as a constituent of the product itself (feedstock or reactant) or as material inputs of the production process. These are referred to as “Resources for material use”.

5.4.2 Land use

5.4.2.1 General

Agriculture and forestry, like any other human activities, use land and at the same time these activities influence the land they use through for example good management practices.

Land use has two aspects: land occupation and land transformation; these can both have effects on for example biotic production potential, biodiversity, ecological soil quality, soil carbon content, soil erosion and freshwater availability. Land use is associated with physical as well as often 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, acidification or climate change.

5.4.2.2 Considerations for modelling land use in LCI

5.4.2.2.1 General

In order to determine the environmental impact of a given land use it is necessary to know for what activity the land is used and the time during which it is used for that particular purpose.

5.4.2.2.2 Area as physical unit

The area used to source the product or raw material is usually defined as land use for agricultural and silvicultural ecosystems. For other ecosystems such as aquaculture the volume may be a relevant measure.

5.4.2.2.3 Distinction of transformation and occupation

Land use includes both land transformation and land occupation and the quantification of land use should consider the following[1],[2]:

— land occupation is measured in m^2 area times time [m^2 x a] per functional unit;

— land transformation is measured in area changed per functional unit [m^2/FU].

Land use transformation addresses the quality change which is induced by changing land use type. This quality change can be directly determined if the land use before transformation is known. The same holds true for the transformation after the occupation period ends.

5.4.2.2.4 Identification of land use type

The determination of the classification system is decisive for the characterization of transformation and occupation as correlations reveal:

— physical-chemical properties of eco-systems (e.g. buffer capacities);

— ecosystem services (e.g. for human use);

— land cover characteristics (e.g. different use intensities).

For inventory modelling, the initial land use and the resulting land use/land cover after occupation should be documented.

Land use types relate to the given activity and are usually classified in schemes. These schemes can comprehensively reveal all different land use types on a global scale or can be adapted to the spectrum of land use types in a given region.

Land use types are specifically related to the human use (agricultural crops, forestry) and can be scaled by the intensity of use.

In order to determine the characteristics of the transformed/occupied entity of land ecosystem and biome, classifications are used. These differ widely in the underlying typology (examples are Holdrige life zones, IPCC classification).

Land use and land cover are also sometimes combined, for example, in Corine land cover classes used to monitor land use and land cover consistently in Europe.

5.4.2.2.5 Land use change in GHG accounting

While in LCI modelling land transformation and occupation is typically considered, there are LCA applications for GHG accounting which use the concept of land use, land use change and forestry (LULUCF) of the IPCC or the concept of direct land use change and indirect land use change (dLUC and iLUC) which is used in the context of the European Renewable Energy Directive.

Indirect land use change considers potential land transformations which are not caused directly by the operator, but may be seen as response of other operators. There is currently no agreed scientific method to characterize indirect land use change in coherence with the modelling principles of LCA. The consideration of potential effects of land transformation in the context of addressing GHG emissions may only be treated as qualitative information and be addressed during the interpretation phase.

Indirect effects can lead to important contribution of the life cycle of products; if they are included for biobased products, they shall at least be considered and included for the products they are compared with as well.

Possible approaches in the methodology are proposed in the European Commission's Joint Research Centre[3].

5.4.3 Water inventory

5.4.3.1 General

Water is of vital importance for quality of nature and almost all human activities, including the production of biomass and therefore the impacts of water use and consumption and on water quality are of crucial importance.

5.4.3.2 Elementary flows

Data related to water which represent elementary flows may be directly collected from unit processes or derived from data, which represent material flows, such as ancillary material or waste for further processing.

The water inventory should include inputs and outputs from each unit process being part of the system to be studied. Any discrepancies in the inventory balance shall be explained.

Generally, information on each elementary flow should include, where relevant:

a) quantities of water used:

   — mass or volume (e.g. water inputs and water outputs);

b) resource types of water used, e.g.:

   — surface water;

— seawater;

— brackish water;

— groundwater (excluding fossil water);

— fossil water;

NOTE 1 Tap water or treated water are not elementary water flows but intermediate flows from a process within the technosphere (e.g. from a water treatment plant).

NOTE 2 Precipitation is not accounted as water input for agriculture and forestry, as it is largely emitted by evaporation and transplantation by the plant and the ground, and which contributes to the natural water cycle, or is incorporated into the output product flow of the system.

c) water quality parameters and/or characteristics, e.g.:

— physical (e.g. thermal), chemical, and biological characteristics, or functional water quality descriptors;

d) forms of water use, e.g.:

— evaporation;

— product integration;

— release into different drainage basins or the sea;

— displacement of water from one water resource type to another water resource type within a drainage basin (e.g. from groundwater to surface water);

— other forms of water used or affected (in-stream use);

e) geographical location of water used or affected (including withdrawal and/or release);

— information on the physical location of water used or affected, including withdrawal and release (as site-specific as needed) or assignment of the physical locations to a category derived from an appropriate classification of drainage basins or regions;

NOTE 3 Environmental condition indicator (e.g. water scarcity, local level of social development, etc.) will require information on the location where the water use takes place.

f) temporal aspects of water use, e.g.:

— time of use and release if relevant residence time occurs within the system boundaries;

g) emissions to air, water and soil with impact on water quality.

NOTE 4 There will be other emissions to air and soil in the product system that do not impact water quality.

Water inputs or water outputs of different resource types, different quality, different form, different location with different environmental condition indicators, or different timing should not be aggregated in the inventory phase. This requirement does not apply when the use of generic databases is permitted. Aggregation may be performed at the impact assessment phase.

Where input and output data for each unit process for the biomass acquisition phase are not available, water used for irrigation, water used for spraying (e.g. fertilisers, pesticides), and water used for the production of those inputs should mentioned in regard to data adequacy and what will be done towards improving the situation and documented in the study.

5.5 Inventory of fossil and biogenic carbon flows

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

NOTE Further guidance can be found in Annex B.

5.6 Guidance for modelling agro-, forestry and aquaculture systems

5.6.1 Modelling agricultural systems

5.6.1.1 General

Agriculture can have positive and negative impacts on the environment. Agricultural crops, such as corn, sugar cane, cassava, palm and castor, can be used as raw materials in biobased products. It is commonly recognized that the following activities/actions related to agriculture, have environmental impacts e.g.:

— use of fertilizers;

— irrigation;

— land occupation and transformation;

— soil management; and

— activities for the production of agricultural inputs such as mineral fertilizers and fuels.

It is noted that agricultural field work is complex, and practices vary significantly across farms and regions. Many parameters influence LCA impacts of agriculture, including intensification and optimization of production practices.

At the same time (resource-, energy-, emission-) efficiency and thus the resulting environmental interventions mirrored in LCA of agricultural production, vary significantly amongst the:

a) type of crop cultivated

b) management regime (fertilizer, pesticide, mechanization, irrigation, tillage practices)

c) soil and climate characteristics (hence location and time),

d) farm practices for (potential) conservation and drying steps of harvest, etc.

The following guidance is intended for practitioners that have to create a new unit process for an agricultural product; in other cases, such data sets, however, can be extracted from existing databases (life cycle inventories). The choice depends on the goal and scope definition of a given study and the corresponding data quality requirements. Where data sets from existing databases are extracted, the following guidance can help to assess the data and documentation quality of the respective data set/life cycle inventory.

5.6.1.2 Key characteristics

5.6.1.2.1 Reference flow

Regarding the reference flow of a given unit process, it is recommended to use a physical unit of mass or volume, together with a parameter of product quality: dry matter content, density, energy content (for example gross calorific value, net energy of lactation, metabolizable energy), oil content, raw protein content or other meaningful and unambiguous characteristics.

EXAMPLE 1 1 kg of rapeseed, dry matter: xx mass-%, oil content: xx-mass%

As agricultural raw products go through various steps of primary production, transport, and conservation, it should be mentioned already in the title /description of the reference flow to which stage of the production or life cycle the system refers, that is, which processes are included.

EXAMPLE 2 Product x, quality y, at the field border / at the farm gate / at the feed mill

The inputs and emissions of the process are related to the reference flow by calculating the ratio of inputs and emissions per produced unit; to this end, it is usually necessary to have information about the yield of the agricultural production. The yield should be documented in units of mass per area. As yields typically significantly vary by year, for annual crops, an average yield on a time-span of at least three years should be derived.

EXAMPLE 3 The following fresh matter yield for grain corn in Germany is reported in the statistical yearbook of agriculture:

— 2007: 9,49 ton/hectare

— 2008: 9,91 ton/hectare

— 2009: 9,20 ton/hectare

— Hence, an average yield of 9,53 ton/hectare is obtained for this region and time period.

5.6.1.2.2 Process-specific background information

To support transparency of the documentation, process and site-specific parameters (depending on the level of detail in the modelling of specific activities) should be documented, for example:

— Distances for all transports involved in the field work, mostly the field-to-farm distance (km by ton dry matter or equivalent unit);

— Climate information: climatic zone and meteorological information, as they can influence plant perspiration (water loss);

— Times of application and condition of spraying: phenomenological growth stage of the plant, soil characteristics, organic remains of previous crops;

— Climatic conditions when spraying, as they influence the mineralisation kinetics, uptake by plants of elements, and emissions into the ecosphere.

5.6.1.2.3 Inventory net interventions

Only the net interventions related to human land management activities should be inventoried. Interventions that would occur also if the site was unused should not be inventoried (e.g. not the basic Nitrate leaching resulting from N input via rain). Of the applied fertilisers and agrochemicals (e.g. fungicides) only the amounts that leave the site (i.e. the field) should be inventoried as emissions to air or water.

5.6.1.3 Exchanges with technosphere

The use of inputs in agricultural production typically (not necessarily) includes seed, fertilizers, lime, pesticides (including growth regulators), fuel for agricultural machinery, other fuel use e.g. for post-harvesting drying of produce or burning weeds, water, agricultural foils, etc. When deriving a new data set (unit process), the quantity and type of the respective input and how it was derived should be described, for example from an agricultural field work protocol. This is helpful for quality assessment, review and potential updates of the input data. The type (name and quality) and quantity of each input should be documented in units of mass or volume per reference flow quantity of the process. In building a product system / life cycle model, all this information is required to derive/identify the corresponding appropriate input data sets / life cycle inventories. Specifically, for fertilizers (mineral and organic), the nutrient content should be specified, in mass percent of N, P_2O_5, K_2O, S, Mg, etc. Specifically, for organic fertilizer the mineralization potential (quantity of fertilizer that can be mineralized or absorbed by the plant produced) should be specified.

Waste flows to waste treatment processes and infrastructure processes are handled analogously. Examples for waste include packaging, agricultural foils after use etc. The type, treatment and amount of waste should be documented in units of mass per reference flow quantity. Examples for infrastructure include agricultural machinery and buildings.

In the modelling of transport processes distances for all transports involved in the field work should be documented, in particular the field-to-farm distance (ton-km or equivalent unit). Explanatory note (adopted from ILCD handbook): Pesticide and fertilizer applications (to the field) are no emission, but part of the product flows within the (man-managed) technosphere.

5.6.1.4 Land occupation and transformation flows

For the modelling of land occupation and land transformation flows, the provisions detailed in 5.4.2 apply. The following additional guidance is provided for land occupation flows of agricultural activities:

To quantify land occupation the use of agricultural/arable land per reference flow quantity (related to yield, see 5.6.1.2.1) and production time has to be known. The production time is the time of the campaign/season, for field crops typically from soil preparation before drilling/seeding to harvest and potential subsequent soil/stubble treatment. The corresponding definition of production time should be documented.

5.6.1.5 Water use flows

The inventory may include the fraction of water withdrawn (e.g. for irrigation) which is not released back to the source of origin, e.g. because of evaporation, evapotranspiration, product integration or release into a different drainage basin or the sea (see 5.4.3).

5.6.1.6 Gaseous emission from agricultural soils

N-based emissions consist primarily of direct and indirect emission of nitrous oxide (N_2O), ammonia (NH_3), and nitrogen oxides (NOx). CO_2 emissions arise from e.g. application of urea, lime, and from mineralization of organic matter in soil, or burning of crop residues. Correspondingly, CO_2 sequestration in the soil (build-up of soil organic matter), where it occurs as a consequence of agricultural management or land use change, can be considered flow of CO_2 from the atmosphere into the system.

The following greenhouse gas emission terms are related to land use and biomass production:

— CO_2 emissions resulting from carbon stock change, related to land use change and improved agricultural management;

— CO_2 emissions resulting from burning of vegetation or dead organic matter as part of land use change process or pre- and post-harvest burning; and

— field emissions, including CH_4 and N_2O, occurring during cultivation as a result of land management.

NOTE Useful guidance can be found in EN 16214-4:2013, 5.2.1 to 5.2.3, 5.3.4 and 5.3.6[4].

Field emissions of N_2O and CH_4 may be calculated in accordance with the IPCC Guidelines[5] or any further update. In the absence of more specific data, the Tier 1 approach as defined in Chapter 11 of the IPCC Guidelines should be used, but the Tier 2 and Tier 3 approach may be used if appropriate data are available.

Furthermore, emission of acidifying gases ammonia (NH_3) and nitrogen oxide (NO) should be included based on a suitable emission model. In the absence of more specific data, literature emission factors may be applied, e.g. the default factor for ammonia in IPCC 2006.

5.6.1.7 Emissions to water

Emissions to water in agricultural activities occur as a consequence of leaching and run-off from agricultural soils. The relevant emissions flows include nitrate, phosphate, organic pollutants and heavy metals stemming from application of fertilizers (mineral as well as organic). A specific methodology or emission model for emissions to water cannot be recommended at present because various approaches exist and can be preferable depending on the goal and scope of a given study and the expertise of the practitioner. The methodology and assumptions applied in the specific case should be documented.

Heavy metal emissions to water bodies should be modelled and inventoried; that means, define heavy metal emission flows as crossing the system boundary to the ecosphere when they leave the agricultural field.

5.6.1.8 Guidance on multi-functional agricultural processes

In general terms, the principles for dealing with multi-functional processes of ISO 14040 and ISO 14044 apply.

Special attention should be paid in modelling of agricultural processes to the following aspects.

A part of the nutrients from fertilisation may remain in the field after harvest and serves as input to the next crop, hence crosses the system boundary within the technosphere over time. In this case, the substance is a co-function of the preceding crop, making that process multi-functional. The general provisions for solving multi-functionality apply.

Intercropping is the practice of growing two or more crops in proximity. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop.

For those cropping elements from such an intercropping system which are harvested, the production process should be handled as a multi-functional process (the general provisions for solving multi-functionality apply). For intercrop elements that are not harvested but remain on the field to improve soil quality or for other beneficial reasons, these are included within the system boundaries of another, primary system/product and should not be treated as a separate process.

5.6.2 Modelling forestry systems

5.6.2.1 Inventory net interventions

Only the net interventions related to human land management activities should be inventoried, e.g. not the basic Nitrate leaching resulting from N input via rain. Of the applied substances (e.g. fertilizers), the amounts that leave the site should be inventories as emissions to air and water.

5.6.2.2 Spatial and temporal boundaries

The spatial and temporal boundaries and approach used for modelling of forest systems is very important for determining all inventory flows and outcome of the study. The spatial and temporal system boundaries should be transparently defined and justified to the goal and scope of the study.

Forests are in principle managed in a region or landscape which is essential to estimate elementary flows appropriately. LCA studies should consider with care the appropriate production unit or scale to include, in relation to the goal and scope of the study.

5.6.2.3 Addressing carbon content

Sustainable Forest Management ensure that carbon stocks in forest stay stable or even improve over time. When modelling forestry systems on landscape level, the biogenic carbon content of harvested wood shall be considered a material inherent property, resulting from the uptake and storage of CO_2 from the atmosphere. A forest management unit managed on a sustainable yield basis should be modelled as a unit process in a steady state with carbon emissions equalling uptake. If modelled on stand level, delays between biogenic carbon emissions and sequestration should be integrated over time.

The spatial and temporal boundaries and assumptions are important to model carbon sequestration and should be set and documented transparently.

5.6.2.4 Land occupation and transformation flows

To address impacts other than GHG emissions from land transformation and land occupation (e.g. biodiversity impacts) the area needs to be determined as important parameter to scale impacts from transformation and occupation as detailed in 5.4.2.

Relevant environmental aspects can be identified by identifying ecosystems services.

A valuable source of information to address transformation and occupation are certification schemes and management plans which detail forest management practices and which may e.g. exclude certain types of transformations (like deforestation) while also requesting a less exclusive/fully reversible occupation.

Multi-functionality of production systems of biomass, e.g. sustainably managed forest, shall be considered according to the rules of co-product allocation in 5.3 when attributing land occupation and land transformation to the functional unit under study.

5.6.3 Modelling aquaculture systems

Aquaculture, algae, marine or freshwater biomass may be used as a basis for biobased products. There are few specific methods existing to assess aquaculture systems.

To establish the LCI for those systems, the guidelines for agriculture may be considered.

5.6.4 Modelling the use-phase in LCAs of biobased products

The use-phase of biobased plastics should be modelled to compare differences between a biobased product and its alternative to provide a service for a certain duration in time. This enables the comparison of the environmental impacts of single-use products with reusable products based on a choice of the same functional unit. This can in particular be relevant in packaging applications, where a single-use products needs to be replaced by a new product to fulfil the same service once more, while the same reusable product can be reused.

5.6.5 Modelling end-of-life processes in LCAs of biobased products

5.6.5.1 General

In this document, focus will be on end-of-life processes of biobased products, even though the relevance of these processes is not restricted to biobased products.

5.6.5.2 End-of-life processes of biobased products

The end of life of biobased products can be particularly impactful, especially when considering single-use application where littering is a known problem. A full assessment of the product's impact should therefore consider likely scenarios for its end-of-life whether it relates to (for instance) reuse, recycling, composting in aerobic or anaerobic conditions, biodegradation in an open environment (such as marine environment), incineration (with energy recovery, or not) landfilling, or disposal in an open environment (littering). Pollution impacts in terms of material and greenhouse gas emission to the environment should be accounted for.

The comparison of biobased plastics should be made taking into consideration all the life cycle stages, with a particular attention to the end of life. An example may be the comparisons between compostable and fossil-based cutlery. Cutlery may arrive at the waste processor plant as a waste system consisting of cutlery, other products and food waste. This aspect has a strong influence on different waste flows (such as food waste flow) and only a consequential LCA approach may provide a correct evaluation of environmental loads. Whether cutlery is compostable or not will significantly change the results as this has an influence also on the other waste flow and on the applicability of the different EoL options (such as composting is a non-efficient option in presence of no compostable materials).

The model on which the end-of-life inventory data are derived from along with any hypothesis and assumptions made shall be clearly documented and reported in the study (e.g. as an Annex). Also, product characteristics such as mineralization rate, composition, etc. shall be reported. Experimental models and/or data may be used as long as scientifically robust.

6 Life cycle impacts assessment (LCIA)

6.1 Impact categories and impact indicators

6.1.1 General

Life cycle impact assessment is covered by ISO 14040:2006, 5.4 and ISO 14044:2006, 4.4. Provisions of these standards shall apply to life cycle impact assessment of biobased products.

6.1.2 Selection of impact categories

A key strength of LCA is the ability to look not just along the life cycle stages but also across a breadth of different impact categories. Restricting an assessment to one impact category, as is done in carbon footprint or water footprint, provides only partial information and thus should not be considered as an environmental assessment of a product.

A well conducted study can help prevent burden shifting, not only between life cycle stages but also between impact categories. ISO 14044 states that the selection of impact categories shall reflect a comprehensive set of environmental issues related to the product system being studied, taking goal and scope into consideration.

Annex C includes a list of impact categories and impact indicators.

6.1.3 Applicability of methods and data

According to ISO 14044, impact categories should be internationally accepted, characterization models and factors scientifically and technically valid and category indicators environmentally relevant. For biomass production systems issues such as scale, geographical or spatial specificity, nonlinearity of effects, reversibility of effects, temporal issues, multi-functionality and appropriate reference situation are particularly relevant to consider in relation to satisfying the given criteria for impact assessment approaches. ISO 14044 also requires to take into account whether the quality of the LCI data and results is sufficient to conduct the LCIA in accordance with the study goal and scope definition.

The impact assessment methodologies for a number of impact categories often considered as particularly relevant for biomaterial systems, e.g. land use, water use, soil degradation and biodiversity are not sufficiently developed to satisfy some or all of the given criteria. This applies to midpoint and end point approaches which include or build on these same categories. It can also be that inventory data are insufficient to support meaningful application of an otherwise acceptable assessment method. Where either of these situations prevails and inventory data indicate potential significance in relation to the goal and scope of the study other information relevant to the system of study and the impact category or categories of concern should be sought and shall be considered in assessment and interpretation, e.g. evidence of accepted good practice and/or conformance with accepted sustainability criteria (see Clause 7).

The evaluation of the robustness of indicators is not simple, and choices of indicators should refer to science-based experts recommendations, such as the Recommendations for Life Cycle Impact

Assessment in the European context provided by the ILCD[6], or in scientific publications (the ProSuite project[7] gives recommendations for biobased products).

6.1.4 Weighting and comparative assertions disclosed to the public

Special attention shall be paid to the LCIA dispositions related to reporting and critical review, as well as to those applicable to comparative assertions intended to be disclosed to the public. ISO 14044 states that weighting should not be used in comparative assertions intended to be disclosed to the public; that category indicators used in this context shall be scientifically and technically valid, and environmentally relevant; and that comparisons shall be conducted category indicator by category indicator.

6.2 Guidelines for specific impact indicators

6.2.1 Treatment of fossil and biogenic carbon in assessing climate change

To calculate the contributions to climate change in the life cycle impact assessment, all biogenic and fossil emissions and removals should be considered. The following approach shall be applied for calculating global warming potential (GWP) for CO_2 emissions and removals related to biomass.

— The CO_2 uptake by biomass is included in the model with negative GWP values in the growth phase and positive GWP values of the substances emitted during the life cycle, and end-of-life.

The biogenic carbon embedded in the biobased product should be equal to the biogenic carbon released in case the end-of-life treatment of the product is complete oxidation. The biogenic carbon can also end up in other products in the case of recycling, stored in landfill or emitted as another greenhouse gas like methane.

Where temporal accounting of GHG emissions is relevant, it should be taken into account but reported separately. Assessment may be carried out according to ISO 14067[8].

6.2.2 Land use

6.2.2.1 General

For the characterization of the inventoried land use several methods with different sets of characterization factors are available. Specific impact assessment methods for land use are recent and there is no scientific consensus on these methods. Any may be used in practice, with a careful preview of the validity and limitations of the method used.

Evidence for responsible sourcing and sustainable management practices can deliver information to address impacts resulting from land use.

Two areas of protection on which land use can have an impact are:

— natural environment/ecosystem quality; and

— ecosystem service/natural resources.

NOTE In LCA, three areas of protection are usually distinguished – human health, natural resources and ecosystem quality.

6.2.2.2 Land use related to natural environment/ecosystem quality

Specific methods for impact on natural environment and ecosystem quality are recent and there is no scientific consensus on those methods. Such methods may be used in practice, with a careful review of the validity and limitations of the method used. Examples for such methods are potentially disappeared fractions (PDF) (ReCIPe) and biodiversity damage potential (BDP) (UNEP/SETAC).

6.2.2.3 Land use related to ecosystem services/natural resources

Specific methods for impact on ecosystem services and natural resources are recent and there is no scientific consensus on those methods. Such methods may be used in practice, with a careful review of the validity and limitations of the method used. Examples for such methods are SOM: Soil organic matter (ILCD handbook[6]) and ecosystem services (guidance is provided by UNEP/SETAC[16]).

6.2.3 Impact of water use

There is no current international acceptance for any single model assessing the impact of water use. The choice of model shall be documented and justified, with a careful review of the validity and limitations of the method used.

In addition to input and output flows in the inventory, ISO 14046[9] describes procedures and requirements to carry out a water impact assessment for instance water scarcity.

If comparative assertions based on LCA are intended to be disclosed into public domain, requirements as set in ISO 14044 and ISO 14025 shall be followed.

7 Interpretation and reporting of LCA

7.1 Interpretation

Guidance and requirements for interpretation are provided in ISO 14040:2006, 5.5 and ISO 14044:2006, 4.5.

The interpretation phase of an LCA serves to draw conclusions out of the inventory and impact assessment phase in view of the goal and scope definition.

Decisions in view of the iterative nature of an LCA study are taken in view of further data collection activities or the reduction of scope due to the limitations in data availability.

The interpretation phase encompasses techniques (e.g. contribution and sensitivity analysis) to understand the significance of LCIA results and relevance of modelling choices. Optional elements which further aggregate results are weighting, sorting and ranking.

Also, data quality and representativeness are evaluated and are assessed in view of their relevance.

In particular for biobased materials the interpretation phase allows also to consider qualitative information e.g. regarding management practices in the production of biomaterials.

In LCA studies where a comparative assertion is intended to be disclosed to the public special care should be paid to ensure that the comparison is valid (see requirements in 4.3.2.7).

In comparison to traditional, existing products, such as glass, paper and fossil-based materials, the new generation of biobased products are often in a relatively early stage of development, and assumptions are needed to portray the life cycle. In LCA studies revealing biobased products, the differences in maturity of products or production systems should be addressed during the Interpretation phase. In case the difference in maturity is too large, LCA comparisons shall not be made. As an example, it does not make any sense when lab scale data are used for the biobased polymer PEF, and directly compared with mature data for fossil-based PET. In such a comparison, future production scenarios for PEF shall be used.

A thorough check of possible inconsistencies and/or different level of detail of inventories should always be performed in comparative studies between biobased products and their alternatives.

Inconsistency can occur when different databases, based on different level of detail and modelling choices, are used. For instance, human toxicity and ecotoxicity impact categories can be affected by this issue due to gaps in the inventory.

NOTE Guidance on how to deal with differences in maturity of production systems will be given in a future part of the ISO 22526 series.

7.2 Reporting of LCA

Also, for biobased products the reporting guidelines provided in ISO 14040:2006, Clause 6 and ISO 14044:2006, Clause 5 shall be followed.

The content of the third-party report – which is mandatory for any type of LCA communication – depends on the intended application; in particular if a comparative assertion is intended to be disclosed to the public.

If a comparative assertion is intended to be disclosed to the public the following information shall apply as additional reporting requirements, otherwise they should be considered.

— sourcing aspects;

— treatment of biogenic carbon in the LCA; and

— treatment of technological maturity.

The only standardized approach to simplify the results out of an LCA is the Type III environmental declaration according to ISO 14025. In LCA, the standardized reporting tool is the third-party report. However, the outcome of both options is still often too complex in business to business and especially business to consumer communication.

7.3 Critical review

Guidance and requirements on critical review are given in ISO 14040:2006, Clause 7 and ISO 14044:2006, Clause 6.

Annex A
(informative)

Example of allocation on glycerol

A.1 Example for the basic approach

Glycerol: The last step of glycerol production is the transesterification of vegetable oils or animal fats into the main product, the biofuel, and the co-product glycerol.

1) Is it possible to subdivide the process in several and distinct processes to avoid allocation?

No as a single reaction (transesterification) is delivering two products.

2) Is it possible to apply system expansion?

No, the glycerol available on the market is produced through various routes where glycerol is also always a co-product (e.g. soap production and fatty acid/alcohol production from various vegetable and animal feedstocks or synthetic glycerol production from propylene).

Conclusion: Allocation is required. As specific physical relationship between products could not be determined, common physical properties can be applied: mass and energy based on energy content.

Results (with illustrative values for allocation method parameters, and also other existing relationships: economic is added) are shown in Table A.1.

Table A.1 — Allocation methods and result

Allocation method	Biodiesel	Glycerol	Allocation for biodiesel	Allocation for glycerol
Energy (NVC)	37 000 MJ/t	17 000 MJ/t	37 000/(37 000 + 17 000*0,05) = 98 %	2 %
Mass	1 t	0,05 t	1/1,05 = 95 %	5 %
Economic (sales price)	1 480 €/t	300 €/t	1 480/(1 480+300*0,05) = 99 %	1 %

In this example, there is no issue on the allocation as the results are similar (all methods reveal an influence of < 5 % impact for glycerol).

Annex B
(informative)

Examples of fossil and biogenic carbon flows accounting and communication

B.1 Example of fossil and biogenic carbon flows accounting

Carbon flows can have two origins: fossil or biogenic. Carbon flows can both come from material resources (fossil and biomass) used as a feedstock of the biobased product and from energy resources (fossil and biomass) used in the production of the product.

Fossil and biogenic carbon emissions both need to be accounted for. In the creation of LCIs for biobased or partially biobased products, sequestration of atmospheric carbon by the plant should be considered. As required under 5.5: “Carbon emissions and removals arising from fossil and biogenic carbon sources and sinks shall be included in the LCI and shall be listed separately in the inventory”.

NOTE 1 The amount of CO_2 taken up in biomass and the equivalent amount of CO_2 emissions from the biomass at the point of complete oxidation results in zero net CO_2 emissions when biomass carbon is not converted into methane, non-methane volatile organic compounds (NMVOC) or other precursor gases.

This subclause describes LCI generation for biogenic and fossil carbon accounting. Emissions from land use change and of non-carbon emissions (e.g. N_2O emissions from farming) should be considered and included in the inventory. However, the specific guidance for calculations of land use change and farming emissions is addressed in 5.4.2.

In this example, fossil carbon flows emitted to the environment, are accounted for as positive flows. The nature of the emissions is identified (e.g. CO_2, CH_4, and other fossil carbon emitted to air, water, soils).

The considered carbon flows in this example are shown in Table B.1.

Table B.1 — Inventory of fossil and biogenic carbon flows

	Inventory flows (quantity)	Nature of emissions
Biogenic carbon		
Atmospheric carbon fixation during biomass growth	- BC1	
Carbon emitted to air/water and soil during production phase	+ BC2	
Carbon permanently sequestered in e.g. co-products or landfilled production wastes [a]	- BC3	
Biogenic carbon embedded	**BC = - BC1 + BC2 - BC3**	
Biogenic carbon emissions to air, water and soil at end-of-life	+ C4	
Net biogenic carbon emissions	**E = BC + C4**	
Fossil carbon		
Fossil carbon emitted to air/water and soil during production phase	+ FC1	
Fossil carbon emissions to air, water and soil during end-of-life	+ FC2	
Total fossil carbon emissions	E’ = FC1 + FC2	

[a] If landfilling of production wastes and partial degradation generates greenhouse gas emissions (e.g. methane, CO_2), those need to be taken into account as well.

