Aerospace-X

Life Cycle Assessment Rulebook

AEROSPACE-X

Version 2.0

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AEROSPACE-X

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Glossary

Term	Definition	Source
Aircraft	An aircraft is any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface.	ICAO, Annex 7, sixth edition
Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.	ISO 14040:2021, 3.17
Attributable process	Those processes that consist of all service, material, and energy flows that become, make, and carry a product throughout its life cycle.	WBCSD Pathfinder
Biogenic carbon	Carbon derived from biomass.	ISO 14067:2018, 3.1.7.2
Carbon offsetting	Mechanism for compensating for a full PCF or a partial PCF through the prevention of the release of, reduction in, or removal of an amount of GHG emissions in a process outside the product system under study.	ISO 14067:2018, 3.1.1.7
Characterization factor	Factor derived from a characterization model, which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator.	ISO 14040:2021, 3.37
Climate change	Impact category in PEF method. All greenhouse gas emissions inventoried in the resource use and emissions profile are weighted in terms of their impact intensity relative to carbon dioxide, which is the reference substance for this category.	PEF 2013/179/EU, 6.1.2
Closed-loop recycling	In a closed loop, the secondary material from one product system is either reused in the same product system (real closed-loop) or used in another product system without changing the inherent technical properties of the material (quasi closed-loop).	ISO 5157:2023, 3.2.6.6
Corporate Sustainability Reporting Directive (CSRD)	EU regulation requiring large and listed companies to disclose regular, audited, and standardized reports on social and environmental risks and impacts.	Directive (EU) 2022/2464
CO_2eq (carbon dioxide equivalent)	Unit for comparing the radiative forcing of a greenhouse gas to that of carbon dioxide.	ISO 14067:2018, 3.1.2.2

Term	Definition	Source
Co-product	Any of two or more products coming from the same unit process or product system.	ISO 14040:2021, 3.10
Cradle-to-gate	System boundary that is applied for a partial LCA that includes a part of the product's life cycle. Cradle-to-gate represents the emissions and removals arising from raw material extraction, up to the point where the product leaves the production site (the "gate"). This explicitly excludes the life cycle stages use and end-of-life.	Adapted from TFS PCF Guideline, ISO 14067:2018, 6.3.4.2, PEF 2013/179/EU
Cut-off criteria	Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study.	ISO 14040:2021, 3.18
Data Quality Rating (DQR)	A quantitative or qualitative assessment of the reliability, completeness, consistency, and representativeness of data used in LCA studies. It supports transparency and comparability across supply chain emissions data.	PEF 2013/179/EU
Declared unit	Quantity of a product for use as a reference unit in the quantification of a partial footprint.	Adapted from ISO 14067:2018, 3.1.3.8
Direct emissions	Emissions from the processes that are owned or controlled by the reporting company.	Adapted from WBCSD Pathfinder
Downstream emissions	Indirect emissions that occur in the value chain following the processes owned or controlled by the reporting company.	Adapted from WBCSD Pathfinder
End-of-Life (EoL)	Begins when the used product is discarded by the user and ends when the product is returned to nature as a waste product or enters another product's life cycle (i.e. as a recycled input).	PEF 2013/179/EU
Functional unit	Quantified performance of a product system for use as a reference unit.	ISO 14040:2021, 3.20
Global warming potential (GWP)	Index, based on radiative properties of GHGs, 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).	ISO 14067:2018, 3.1.2.4
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.	ISO 14067:2018, 3.1.2.1

Term	Definition	Source
Homogeneous product	A product that shares key physical characteristics, materials, and production processes with others in its group, differing only by parameters that systematically affect its environmental footprint.	Catena-X PCF Rulebook v4.0
Homogeneous part	A part produced using identical materials and manufacturing processes across instances, with negligible variation in characteristics affecting the footprint. Such parts can be treated as equivalent for LCA calculation.	Adapted from Catena-X PCF Rulebook v4.0
International Aerospace Environmental Group (IAEG)	A non-profit organization of global aerospace companies created to collaborate on and share innovative environmental solutions for the aerospace industry.	IAEG, “About IAEG”
ILCD Format	International Life Cycle Data System Format.	ILCD
Input	Product, material, or energy flow that enters a unit process. Products and materials include raw materials, intermediate products and co-products.	ISO 14040:2021, 3.21
Land use	Human use or management of land within the relevant boundary.	ISO 14067:2018, 3.1.7.4
Life cycle	Consecutive and interlinked stages related to a product, from raw material acquisition or generation from natural resources to end-of-life treatment.	ISO 14040:2018, 3.1
Life Cycle Assessment (LCA)	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.	ISO 14040:2018, 3.2
Life cycle emissions	The sum of emissions resulting from all stages of the life cycle of a product and within the specified boundaries of the product.	Adapted from WBCSD Pathfinder
Life cycle impact assessment (LCIA)	The phase of LCA that evaluates the magnitude and significance of environmental impacts based on the inventory of inputs and emissions. It translates resource use and emissions into impact indicators (e.g. climate change, acidification).	ISO 14040:2021, 3.4
Life cycle inventory analysis (LCI)	The phase of Life Cycle Assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.	ISO 14040:2021, 3.3

Term	Definition	Source
Material	Physical goods that are further processed (and not consumed) in manufacturing processes.	Adapted from WBCSD Pathfinder
Net zero CO_2 emissions	Net zero CO_2 emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period. Net zero CO_2 emissions are also referred to as carbon neutrality.	IPCC glossary
Output	Product, material, or energy that leaves a unit process. Products and materials include raw materials, intermediate products, co-products and releases.	ISO 14040:2021, 3.25
Packaging	Product to be used for the containment, protection, handling, delivery, storage, transport and presentation of goods, from raw materials to processed goods, from the producer to the user or consumer, including processor, assembler or other intermediary.	ISO 21067:2016 2.1.1
Paris Agreement	The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) was adopted on December 2015 in Paris, France, at the 21st session of the Conference of the Parties (COP) to the UNFCCC. The agreement, adopted by 196 Parties to the UNFCCC, entered into force on November 4, 2016 and as of May 2018 had 195 Signatories and was ratified by 177 Parties. One of the goals of the Paris Agreement is “Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels”, recognizing that this would significantly reduce the risks and impacts of climate change. […]	IPCC Glossary
Partial LCA	Environmental impacts of one or more selected process(es) in a product system according to the system boundary with the selected stages or processes within the life cycle.	In accordance with ISO 14040:2021, A1.2
Partial PCF	Sum of GHG emissions and GHG removals of one or more selected process(es) in a product system, expressed as carbon dioxide equivalents and based on the selected stages or processes within the life cycle.	ISO 14067:2018, 3.1.1.2
Primary data	Primary data is a quantified value of a process, or an activity obtained from a direct measurement or a calculation based on direct measurements. Primary data can include greenhouse gas emission factors and/or greenhouse gas activity data.	14067:2018, 3.1.6.1

Term	Definition	Source
Primary material	Virgin material.	PEF 2013/179/EU
Process	Set of interrelated or interacting activities that transform inputs into outputs.	ISO 14040:2021, 3.11
Product	Any good (tangible product) or service (intangible product).	ISO 14040:2021, 3.9
Product carbon footprint (PCF)	Sum of GHG emissions and GHG removals in a product system, expressed as CO_2 equivalents and based on a Life Cycle Assessment using the single impact category of climate change.	Adapted from ISO 14067:2018, 3.1.1.1
Product Carbon Footprint system model	Mathematical representation of a physical system and the incorporated processes to calculate a PCF.	Catena-X PCF Verification Guideline
Product category	Group of products that can fulfill equivalent functions.	ISO 14067:2018, 3.1.1.8
Product category rules (PCR)	A set of specific rules, requirements, and guidelines for developing Type III environmental declarations and footprint communications for one or more product categories.	ISO 14067:2019, 3.1.1.9
Product Environmental Footprint (PEF)	PEF is a multi-criteria measure of the environmental performance of a good or service throughout its life cycle. Considering extraction of raw materials, through production and use, to final waste management.	Adapted from PEF 2013/179/EU
Product system	Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product.	Adapted from ISO 14040:2021, 3.28
Raw material	Primary or secondary material that is used to produce a product. Secondary material includes recycled material.	ISO 14040:2021, 3.15
Reference flow	Measure of the inputs to or outputs from processes in a given product system required to fulfil the function expressed by the functional unit.	ISO 14040:2021, 3.29
Renewable energy	Energy from renewable sources' or 'renewable energy' means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas.	Renewable Energy Directive (2018/2001)

Term	Definition	Source
Representative product	The representative product can be a real or an averaged (non-existing) product. The averaged product should be calculated based on sales-weighted characteristics of all technologies/materials used in the company's production system.	Catena-X PCF Rulebook v4.0
Risk management	Plans, actions, strategies, or policies to reduce the likelihood and/or consequences of risks or to respond to consequences.	IPCC Glossary
Secondary data	Data which does not fulfil the requirements for primary data. 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.	ISO 14067:2018, 3.1.6.3
Secondary material	Secondary material includes reused or recycled material.	PEF 2013/179/EU
Sectoral guideline	LCA reporting rules issued by industry associations or initiatives as guidance for their members.	
Supplier gate	The supplier's factory (out-bound) gate through which the product leaves the production site and is ready for shipment to the customer.	Catena-X PCF Rulebook v4.0
Supply chain	Those involved, through upstream and downstream linkages, in processes and activities relating to the provision of products to the user.	ISO 14067:2018, 3.1.5.2
Sustainability	A dynamic process that guarantees the persistence of natural and human systems in an equitable manner.	IPCC Glossary
System boundary	Boundary based on a set of criteria representing which unit processes are a part of the system under study.	ISO 14040:2021, 3.32
Transport / distribution packaging	Packaging designed to contain one or more articles or packages, or bulk material, for the purposes of transport, handling and/or distribution.	ISO 21067:2016, 2.2.6
Unit process	Smallest element considered in the life cycle inventory analysis for which input, and output data are quantified.	ISO 14040:2021, 3.34
Upstream emissions	Indirect emissions that occur in the value chain prior to the processes owned or controlled by the reporting company. All upstream transportation emissions are also included as part of upstream emissions.	Adapted from WBCSD Pathfinder

Term	Definition	Source
Use stage	That part of the life cycle of a product that occurs between the transfer of the product to the consumer and the end-of-life of the product.	Adapted from WBCSD Pathfinder
Value chain	All the upstream and downstream activities associated with the product system.	Catena-X PCF Rulebook v4.0
Waste	Materials, products, or emissions without economic value that the holder intends or is required to dispose of.	Adapted from ISO 14040:2021, 3.35

1 Introduction

1.1 Purpose and scope of the rulebook

The Aerospace-X (AX) Life Cycle Assessment (LCA) rulebook is a comprehensive document outlining specific guidelines for the assessment of environmental impacts in the aerospace industry using the LCA technique. Providing a standardized common framework for conducting LCAs, reducing variability and improving comparability across products is the main aim of the rulebook. Additionally, enhancing data quality by establishing clear data quality requirements to ensure reliable and accurate calculations is also the purpose of the rulebook. This establishes a standard for sharing high-quality and consistent LCA data between the supply chain partners enabling a collaborative effort to reduce environmental impacts.

This rulebook defines rules specific to the aerospace supply chain with the aim of improving clarity on the standards ISO 14040/44 and ISO 14067. Since the aerospace supply chain is complex and spread across multiple sectors, the LCA technique is closely aligned with broader guidelines such as Catena-X PCF Rulebook, WBCSD Pathfinder Framework, GHG Protocol Product Standard and IAEG Aerospace LCA Framework allowing for interoperability.[1,2,3,4]

1.2 Life Cycle Assessment in the aerospace industry

The aerospace sector is an emission-intensive industry, contributing approximately 4% of direct greenhouse gas (GHG) emissions in the EU in 2022 and experiencing rapid growth.[5] This increase is driven by a growing demand for mobility. In response, the EU Green Deal has set a target of becoming climate neutral by 2050. Achieving this goal will require significant efforts from the aerospace industry to reduce its emissions. It is therefore imperative for the aerospace industry to calculate its emissions in order to identify opportunities for improvement and minimise its environmental impact to achieve climate targets.

The ISO 14040 and 14044 standards are widely used as the basis for conducting LCAs and are also forming the basis for this rulebook. Given the significance of carbon neutrality, particular attention is paid to the impact category climate change, which in turn enables the calculation of the Product Carbon Footprints (PCF) at product level. The foundation for this approach is the ISO 14067 standard.

To date, conducting LCAs / PCFs in the aerospace industry has tended to be implemented at company level as part of compliance with the Corporate Sustainability Reporting Directive

[1] Catena-X Automotive Network. *Catena-X Product Carbon Footprint Rulebook (Version 4.0)*. August 2025. PCF Rulebook v4.0 | Catena-X - Library

[2] World Business Council for Sustainable Development (WBCSD). *Pathfinder Framework for Product Life Cycle Emissions Accounting and Exchange (Version 2.0)*. 2023. Pathfinder Framework Version 2.0 | WBCSD

[3] Greenhouse Gas Protocol. *Product Life Cycle Accounting and Reporting Standard*. World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD), 2011. Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf

[4] International Aerospace Environmental Group (IAEG). *Aerospace Life Cycle Assessment (LCA) Framework for Improved Connectivity (Version 01)*. April 2025. wg12-lca-frmwk-document-_v1_final.pdf

[5] European Commission. (2025). *Reducing emissions from aviation*. Climate Action. https://climate.ec.europa.eu/eu-action/transport-decarbonisation/reducing-emissions-aviation

(CSRD). Due to large data gaps in the supply chain, it is difficult to calculate the environmental impact at product level. Various approaches exist for LCA and PCF, however they leave room for interpretation, which leads to intransparency and differences in calculation and eventually to wrong conclusions. The rulebook aims to set an industry wide approach.

In order to ensure a consistent calculation across the entire value chain, a standardized procedure must be implemented throughout all stakeholders in order to determine the environmental footprint on product level. The Catena-X (CX) PCF Rulebook already provides a sound basis for calculating PCFs. This builds the basis for the aerospace industry, as suppliers may deliver to both the aerospace and automotive industry. In the AX LCA Rulebook, the principles of CX are extended in order to create the basis for carrying out a holistic assessment of environmental impacts.

2 Framework

2.1 Version

This document represents version 2.0 of the AX LCA Rulebook, released in 06/2026. LCAs shall be conducted according to the most current version of this rulebook.

2.2 Terminology

Clarification on ISO terminology used in the rulebook:

- Shall: indicates mandatory requirements for compliance with the AX LCA Rulebook.
- Should: indicates a recommendation. Any deviations must be justified and clearly documented by the party conducting the study.
- May: indicates an option that is allowed.
- Can: indicates that something is possible, such as an organization or individual having the capability to do something.

Further definitions of frequently used terms can be found in the Glossary.

2.3 Topics out of scope

The AX LCA Rulebook is focused on the production phase of aircraft, covering PCF and LCA, accounting from cradle-to-(factory)gate for aircraft, products and materials. Recycling is currently only included through the use of secondary materials (section 5.2.3). Comprehensive recycling strategies require additional methods, which are currently beyond the scope of this rulebook and will be considered in later versions.

In this second version of the AX LCA Rulebook, six impact categories are considered (see chapter 6). However, it is intended that further impact categories will be added to the AX LCA Rulebook in order to reflect a comprehensive set of environmental issues related to the product system being studied.

2.4 Catena-X as the basis for the rulebook

The AX LCA Rulebook uses the CX PCF Version 4 rulebook as a foundation, adapting its structure and methods to suit the needs of the aviation industry. Building on an existing, recognized framework, it helps streamline methods and clarify expectations for data handling and reporting while allowing for sector-specific adjustments, where necessary. An explanation of the application of the CX PCF Rulebook and the specific adjustments made for the aerospace context can be found in the annex.

2.5 Transition period

This document foresees a transition period after publication of this version to facilitate the initial implementation of the rulebook in the industry. Sections marked as “after the transition period” are voluntary within the transition period. After the transition period, these sections are planned to substitute the sections marked as “within transition period” and will thus become mandatory. The transition period will last until end of 2027.

3 Existing methods and standards

3.1 Relationship

The AX LCA Rulebook is based on the CX PCF Rulebook, the IAEG LCA Framework, the LCA standards ISO 14040/44 and the PCF standard ISO 14067 (Figure 1).

Figure 1. Relationship of standards

The AX LCA Rulebook further specifies existing standards and, if applicable, refers to sectoral guidance and product category rules for LCA in aerospace supply chains. The AX LCA Rulebook is closely aligned with the IAEG Aerospace LCA Framework, the GHG Protocol Standard and the WBCSD Pathfinder Framework. Alignments with sector initiatives such as Together for Sustainability (TfS), worldsteel, International Aluminum Institute (IAI), European Aluminum, Aluminum Stewardship Initiative have been initiated.

3.2 Hierarchy of conformity

Existing rules shall be applied according to the following hierarchy:

1. The LCA shall be conducted in accordance with ISO 14040 and ISO 14044.

2. Aerospace supply chain-specific requirements shall be applied as defined in this document.

3. Sector-specific and product-specific rules should be applied if prescribed within this rulebook.

Information on the applied methods or standards shall be shared downstream as part of the LCA Data Model (Section 8.1) to create greater transparency and enable comparability.

4 Scope and system boundary

The AX rules are based on the attributional LCA approach. This approach seeks to determine the environmental impacts associated with a product throughout its life cycle. ISO 14040 and ISO 14044 build a structured technique for assessing the environmental impacts of products and processes over their complete life cycle. However, these standards are designed for broad applicability and do not address the specific requirements of aerospace systems.[6] This section presents AX's sector-specific guidance on defining system boundaries and scope, addressing life cycle stages, and selecting impact categories and calculation methods to promote methodological consistency within the aerospace industry.

4.1 Introduction to LCA and PCF methodology

LCA, standardized under ISO 14040 and ISO 14044, evaluates inputs, outputs and environmental impacts associated with a product, process, or service over its life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave). As defined in 14040 an LCA consists of four phases: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation. Depending on the objective of the study, only individual phases of the life cycle may be considered (i.e. cradle-to-gate, gate-to-gate). The selection of impact categories in an LCA reflects a comprehensive set of environmental issues related to the product system being studied, including climate change, land use, water consumption, and resource depletion (ISO 14044). LCA involves compiling a Life Cycle Inventory (LCI), which quantifies all physical flows, inputs and outputs of materials, energy, and emissions. These inventory results are then used in the Life Cycle Impact Assessment (LCIA), where environmental impacts are calculated using characterization models. This provides the basis for interpreting trade-offs and informing design decisions aimed at sustainability and circularity.

In contrast, the PCF focuses exclusively on greenhouse gas (GHG) emissions, covering gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and others as defined in ISO 14067 and the GHG Protocol. The PCF is typically expressed in kg CO_2 equivalents and is often treated as equivalent to the climate change impact category in LCIA. Although often associated with radiative forcing, GHGs like CO_2 can have broader environmental interactions, including roles in biogenic carbon cycles. PCF enables consistent product-level comparisons and supports carbon labeling. However, it excludes non-climate-related environmental impacts, making it a narrower, GHG-specific subset of LCA.

LCA is a relative approach, which is structured around a functional unit. This functional unit defines what is being studied. All inputs and outputs in the LCI and consequently the LCIA and subsequent analysis are related to the functional unit.

It is imperative that the goal and scope of an LCA are clearly defined. Aspects such as the functional unit, system boundaries, allocation procedures, LCIA methodology and data requirements are addressed hereafter.

[6] IAEG (2025) - Aerospace Life Cycle Assessment: Framework for improved connectivity, 15.

Once the goal and scope of an LCA are defined, all (relevant) inputs and outputs for a product throughout its life cycle are being compiled and quantified. This is called the LCI. The data that is collected includes:

- energy inputs, raw material inputs, ancillary inputs, other physical inputs,
- products, co-products and waste,
- releases to air, water and soil and
- other environmental aspects.

The next step is to evaluate the extent and significance of the potential environmental impacts of all inputs and outputs and for the product in total. This is done in the LCIA, where physical flows (LCI results) are translated into potential impacts (classified in impact categories) on the environment using scientifically derived characterization factors specific to each category.

LCA considers several attributes or aspects of the natural environment, human health and resources. By considering several attributes and aspects within one study, potential trade-offs can be identified and assessed. The selection of impact categories and methodology for impact assessment is part of the scope definition and based on the goal defined for an LCA. Often, predefined sets of impact categories, category indicators and characterization models are used, for example the EF 3.0 or ReCiPe 2016 methodology.

4.2 Functional and declared unit

The PCF / LCA shall be assessed for a functional unit (FU). The functional unit represents a quantified expression of the function(s) delivered by the system under study. It acts as the reference basis for all input and output data within the LCA. This unit captures and defines the essential product characteristics – such as performance, appearance, durability, and maintainability – that are required for a valid comparison, based on specifications driven by customer or market demands. Its role is fundamental, as it enables the consistent and meaningful comparison of alternative products or systems by standardizing the basis of assessment.[7] (Example: the functional unit for an aircraft can be defined as “Transport of X passenger / Y kg payload over a distance of Z nautical miles.”)

In cases where a functional unit cannot be meaningfully defined – especially in partial PCF / LCA studies or for intermediate products – a declared unit shall be used as the reference unit for quantifying the environmental impact of the product. In aerospace applications, the declared unit is especially appropriate for intermediate products whose full function and lifecycle context may not be visible to the supplier (e.g. coatings, fasteners, or semi-finished materials). In such cases, mass- or count-based declared units allow consistent LCA data transfer across stakeholders. Possible declared units are piece, kilogram, liter, cubic meter, kilowatt hour, megajoule, ton kilometer, square meter, hour and megabit second.

Additionally, a functional aspect is suggested to be added to the declared unit by the recipient depending on the comparison to be done.

- For countable products (i.e. a component or part) the declared unit shall be 1 piece as described in the part description including a defined weight and the part ID.

[7] IAEG (2025) - Aerospace Life Cycle Assessment: Framework for improved connectivity, 18-19.

- For materials, i.e., mass products or commodities, the declared unit shall be 1 kg of product, regardless of its state (solid, liquid, gas), as its specific density is considered.
- If packaging is included, the declared unit is 1 kg or 1 piece of unpackaged product at the factory gate.

A transformation of the declared unit shall be feasible using a functional conversion factor, this factor may consider the following aspects:

- Lifetime of the product
- Mechanical or thermal properties

4.3 System boundaries and completeness requirements

The definition of the system boundary is the basis to determine which unit processes are included within the LCA study. The life cycle of a product can be divided into the following five stages: (1) raw material extraction, (2) production, (3) distribution and storage, (4) use of product and (5) end-of-life. There are different cradle-to-x approaches depending on the phases that lie within the observation scope. The AX LCA scope of version 2 consists of the raw material extraction, production and distribution and storage phases, which corresponds to the cradle-to-gate approach (Figure 2). This partial LCA can be exchanged along the entire production supply chain, resulting in the LCA of the production of the final product.

The cradle-to-gate approach of this regulation includes all attributable upstream emissions and those directly associated with production, including all transport activities. Life cycle emissions not included in this regulation are any downstream emissions associated with the use of the product and its end of life.

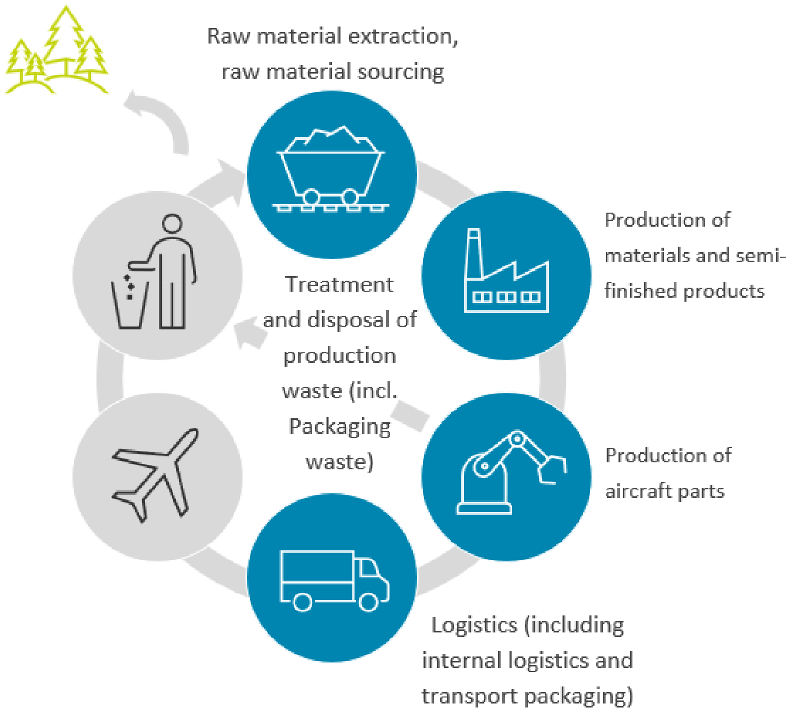


Figure 2. System boundaries for AX LCA

For a better overview and transparency, companies shall list all attributable processes of their product that are part of the cradle-to-gate scope.

The AX LCA Rulebook boundaries are therefore:

- Raw material extraction, raw material sourcing
- Production of materials and semi-finished products
- Production of aircraft parts
- Packaging of aircraft parts, including all operations required for performing packaging
- Treatment and disposal of production waste (incl. packaging waste)
- Logistics (including internal logistics and transport packaging, refer to section 5.2.1)
- Quality control in production
- IT for process and manufacturing control

Processes that lie within the system boundaries but have no relevant influence are excluded based on the cut-off rules described in section 4.3.1. In general, resource use and emissions that are not directly associated with the production system relevant to the product are excluded from the system boundaries. These include, among others:

- Employee commuting and work travel
- Research and development, administration, or sales processes
- Emissions from construction or dismantling of capital goods (such as buildings, manufacturing equipment or any other infrastructure for transport, media or energy distribution and energy generation, within or outside the control of the company)

4.3.1 Cut-off rules

All materials and processes included in the product system need to be considered if feasible. Alternatively for complex systems, the most significant environmental impacts can be considered. This means that processes contributing less than 3% to the total environmental impact may be excluded. This 97% coverage shall be achieved and documented in a screening analysis.

4.3.2 Initial screening analysis

An initial screening of the LCI of (a) representative product(s) / service(s) shall be performed by the company calculating LCAs, referred to as the screening step. The screening pursues the goal to point out needs of action in terms of data collection activities or activities to improve data quality. A screening shall include the LCIA for the impact category Global Warming Potential (during the first transition period) and allow further refinement of the PCF system model of the product(s) / service(s) in scope in an iterative manner as more information becomes available. Within screening, no exemption is allowed, and readily available primary or secondary data may be used, fulfilling the data quality requirements to the extent possible. To estimate 97% coverage, it is assumed that the PCF data received from suppliers and the emission factors represent the full upstream supply chain. This is necessary because it's not possible to directly measure or verify the actual coverage of all upstream activities. Once the screening is performed, the initial scope settings may be refined. The representative product approach and a description of the excluded attributable processes shall be documented.

The screening analysis shall be updated at the end of the transition period of the AX LCA Rulebook, so that possible changes of significant activities can be considered, especially for further impact categories.

4.4 LCI modelling framework and handling of multifunctional processes

Once the LCA scope and functional / declared unit have been defined, a system model should be constructed. The model for the product, component or system should contain:

- A Bill of Materials (BoM) or equivalent input data.
- A flow diagram that defines the system boundary and identifies all actors.
- Complete set of assumptions for transportation.

Modelling should be set at a level that permits meaningful comparison among products performing the same function. The model applied in an aerospace LCA should:

- Quantify every impact category and pinpoint the most relevant ones, along with the applicable life-cycle stages, processes, and direct elementary flows.
- Facilitate comparison between products that share the same function or application.
- Calculate benchmarks against a representative product or system when available.
- Define performance classes, if appropriate.

The LCA should describe every step taken to define the representative product or system model(s) in the study and record the information obtained while safeguarding confidential data. Any information collected during the LCA that is deemed confidential (due to competitive business considerations, intellectual property rights, or other legal constraints) shall not be disclosed publicly under any circumstances. Developed models should be presented to and discussed with the relevant stakeholders.[8]

If any process within the system model produces more than one major output (i.e., a multifunctional process where co-products are produced), system expansion or the allocation hierarchy defined in Section 5.1.2 shall be followed.

4.5 Conducting the LCIA

In the LCIA phase, the data collected in the LCI is translated into environmental impacts. By classification each emission and resource flow from the inventory is assigned to its corresponding impact category. Characterization then converts these flows into comparable impact results using scientifically derived characterization factors

For the aerospace sector, the LCIA phase should apply a standardized, robust method to ensure comparability and regulatory alignment. Based on IAEG LCA Aerospace Framework, the Environmental Footprint (EF) LCIA method is recommended with a specific focus on the impact categories described in section 6.

[8] IAEG (2025) - Aerospace Life Cycle Assessment: Framework for improved connectivity, 24-25.

5 Principles for calculation of LCA and PCF

5.1 Accounting for LCA / PCF

System boundaries shall include all attributable processes that comply with the cut-off criteria (Section 4.3.1).

5.1.1 Calculation

To be included in the supplementary LCA guidance document[9].

5.1.2 Allocation process

Allocation occurs when a process or system generates multiple outputs (co-products), requiring the distribution of environmental impacts among them. Allocation shall be avoided whenever possible. If allocation cannot be avoided, follow the approach in Figure 3. This approach follows the hierarchy from IAEG Aerospace LCA Framework and is adapted from CX PCF Rulebook.

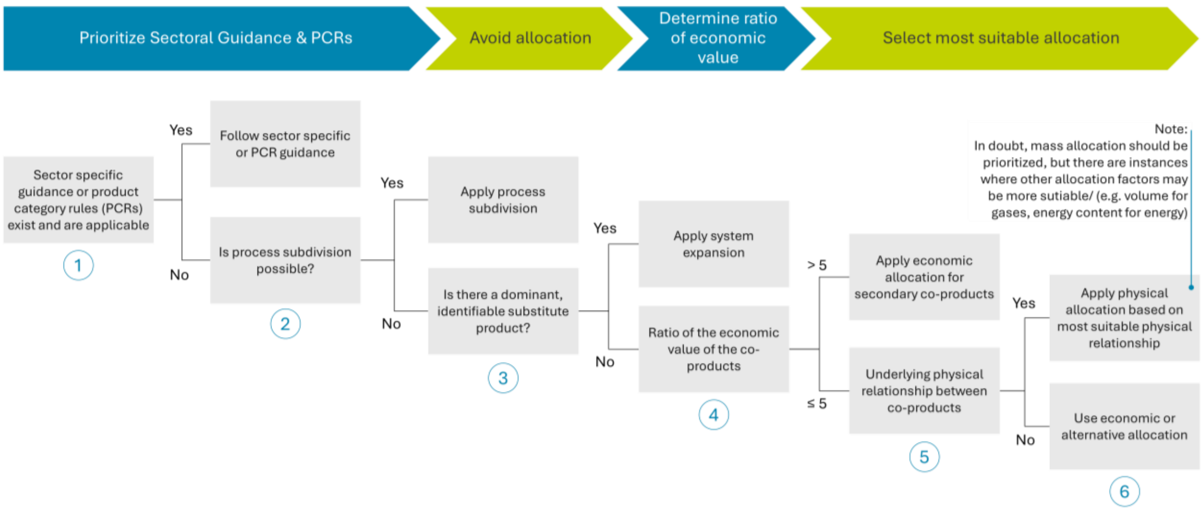


Figure 3. Multi-output allocation decision procedure

(1) If sector-specific guidance or a PCR exists, a legal entity producing a product belonging to a category in this sector shall follow this guidance or PCR to identify the adequate multi-output allocation approach. This shall be declared in the data model including the respective reason for using the PCR.

(2) If no approved sectoral guidance/PCR is available and subdivision is possible, subdivision shall be applied. Subdivision refers to disaggregation of multifunctional processes / facilities to isolate input flows directly associated with each process or facility output.

(3) If subdivision can not be applied, but a dominant substitute product can be identified, expanding the product system to include additional functions related to co-products shall be applied. System expansion via substitution shall only be used in accordance with:

[9] https://www.aerospace-x.net/en/about-us/aerospace-x-one-pager.html

System expansion via substitution should only be used if there is a dominant, identifiable displaced product and production path for the displaced product based on sector consensus. Dominant means that the production process is the main process on the market. For the emissions data, primary data shall be used and secondary data may only be used if primary data isn't available. In case of secondary data, the requirements in section 7.2 shall apply to guarantee that the dataset and source for calculating system expansion credits are compliant. If no sector consensus exists, following requirements shall be fulfilled:

- The production of the co-product is an integral part of the production process.
- The alternative dataset must be representative of the dominant production route and comply with the requirements of section 7.2.
- A clear description of the process for selecting the alternative product substituted by the co-product shall be internally documented.

Double counting shall be avoided. No market-mediated effects shall be applied, as the attributional LCA approach shall be used (see 4.1). The customer of the co-product can be provided with LCA results of the co-product. This enables the customer of the co-product to account for the co-product's correct footprint and prevents double counting of credits.

(4) If allocation can't be avoided, subdivision isn't possible, no dominant substitute product can be identified, companies shall calculate the ratio of the economic value of the reference product to each co-product per declared unit. This ratio is employed in the next step of the decision tree to determine the most suitable allocation approach. For the use of economic values, prices as shown in the hierarchy below shall be averaged over the last 3-5 years to smooth out fluctuations.

(5) If the calculated economic value ratio is equal or lower than five, companies shall apply allocation using a physical relationship to partition inputs and outputs between the studied co-product(s). The physical relationships to choose from are:

- produced masses,
- produced pieces,
- contained exergy,
- contained energy.

(6) If the calculated ratio is higher than five, companies shall apply an economic allocation using economic value as criterion to partition inputs and outputs between the studied co-product(s). For the determination and use of economic allocation factors, the following hierarchy shall be applied. Only one type of economic allocation factor shall be chosen consistently in the order of priority of the hierarchy. Only if the respective prioritized factor is not available, the next factor in the hierarchy may be chosen. The chosen factor shall always be averaged over 3-5 years to smooth out fluctuations. A systematic approach should be internally documented for materials with high fluctuations of the selected factor of price/ cost.

1) Global market price (global market prices, usually only available for commodities).
2) Regional market price.

3) Other economic allocation factors (i.e., production costs or sales price).

5.2 Additional principles

5.2.1 Transportation from supplier to customer

In addition to emissions from production and manufacturing, there are also emissions from the transportation of products. All upstream transportation processes shall be included in the calculation of environmental impacts, i.e. included in the cradle-to-gate system boundary. The same applies to in-house logistics unless cut-off rules apply (see Figure 4). This section deals with transportation from a supplier to its customer. The cradle-to-gate boundaries end at the suppliers' outbound gates. This boundary applies independently from the responsibilities in economic or operative terms for transportation processes (Figure 4).

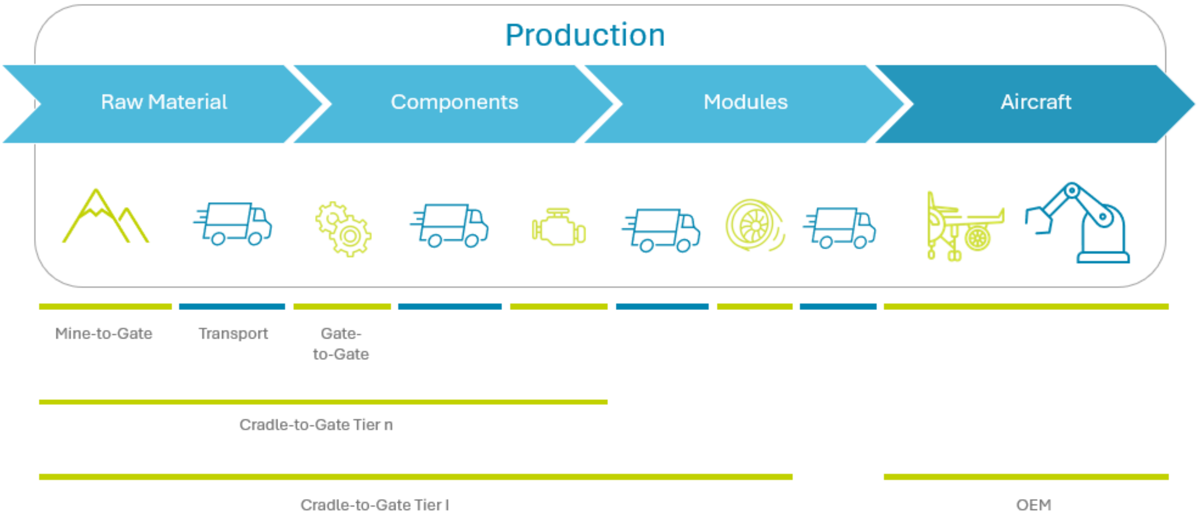
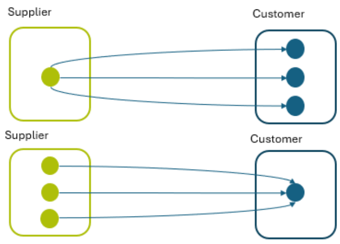
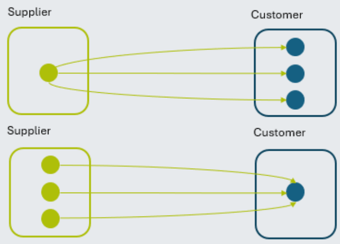


Figure 4. Definition of scopes

Nonetheless, if a supplier is responsible in economic or operative terms for the outbound logistics (i.e., transportation from the supplier to its customer), the supplier shall report the environmental impacts from this transportation in addition to and separately from the cradle-to-gate environmental impacts. Otherwise, the customer shall account for transportation between the supplier’s and its own shipping site (factory gate or distribution center, see Table 1).

Table 1. Transportation between supplier and customer.
The responsibility of accounting for emissions from transport depends on which party is responsible in economic or operative terms.

Case	Description	Economic/operative responsibility for transportation from supplier to customer	Accounting for transportation emissions
1	Multiple shipping sites, and/or multiple unloading sites 	Inbound transportation contracted or operated by customer	Customer responsible for quantification of transportation emissions. As for multiple transportation relations, emissions shall be attributed by mass between the respective products
2	Multiple shipping sites, and/or multiple unloading sites 	Outbound transportation contracted or operated by supplier	Transportation emissions to be reported separately by supplier to the customer (additionally to supplier's PCF). As for multiple transportation relations, emissions shall be attributed by mass between the respective products

Further Clarification on Responsibility and Documentation:

- Transport emissions shall be assessed by the party implementing the transportation process, based on actual data or accepted modeling methods.
- External transport emissions occurring at the supplier–customer interface shall be documented separately, and this documentation must be exchanged between parties during the data handover.

Transports from production sites to suppliers' distribution centers are deemed as suppliers' in-house logistics (see Figure 5), i.e., the distribution center is regarded as the shipping point. The same applies to the customer (see Figure 6).

Figure 5. Distribution center supplier side

Figure 6. Distribution center customer side

Regardless of whether transportation emissions are quantified by a supplier or a customer, they shall be consolidated within the customers' calculation of environmental impacts.

5.2.1.1 System boundaries for transportation

Emissions from transportation shall cover emissions from well-to-wheel, i.e., the system boundaries span from energy provision, production and distribution ending at the transportation operation itself. Emissions from the production of the transportation means the infrastructure, e.g., roads, vehicles, ships and railways, shall not be included (see Figure 7).

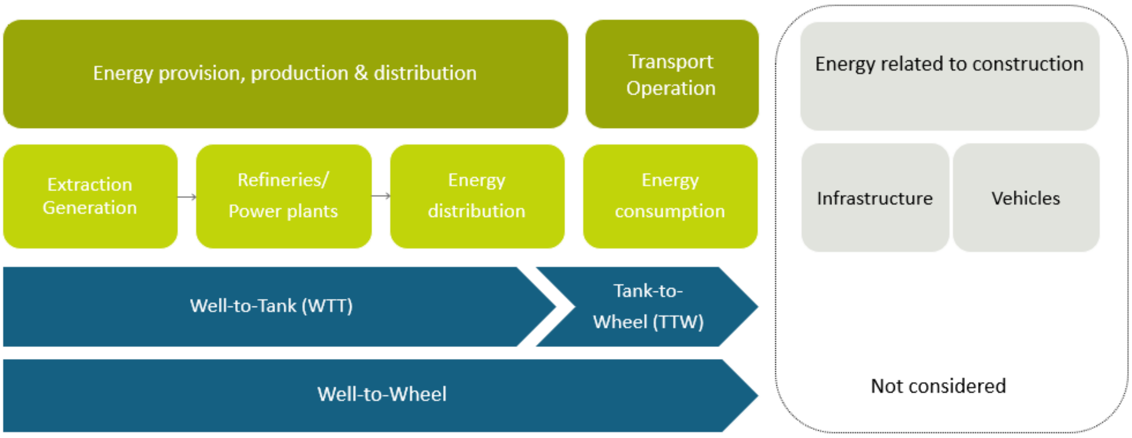


Figure 7. System boundaries for transportation

In case of transport chains (transport of a product by more than one transport mode) the chain links shall be individually quantified and subsequently summed up.

5.2.1.2 Data sources for transportation

Consistent with the AX goal of basing LCA quantification on primary data, the ultimate approach of quantifying transportation emissions shall be based on measuring the fuel and energy consumption of a trip and multiplying it by the emission factor of the fuel/energy that covers all upstream emissions of the fuel/energy. Only transport emissions quantified on the basis of measured fuel/energy consumption shall be considered as primary data. In case of collective transport, the primary data based transport emissions require allocation to the individual product. Such allocations do not change the classification of emission data as being primary data. Direct measurement of fuel/energy consumption of a transport operation may however not always be possible and modelling transport emissions is required. Calculation of transport emissions shall follow the recommendation set out in the GLEC Framework V3.0, except for the mandate to include emissions from the construction and dismantling of energy infrastructure. The GLEC framework allows for three approaches to establish transport distances: shortest feasible distance (SFD), great circle distance (GCD) and actual distance. These approaches shall be used according to the following hierarchy:

- Actual distance
- SFD
- GCD

Emissions reduction from the use of low-carbon fuels may only be claimed if a statement of sustainability (origin and emissions reduction) for the fuel is provided as issued by a bonded warehouse. A tradeable certificate is required.

5.2.2 Accounting for waste treatment

Waste is any material or process output which is not deliberately produced as an integral part of a multi-output production process. No further use of the material or process output is certain.

Additionally, the holder discards or intends to discard or is legally required to discard the residue based on national waste legislation. Waste materials with certain further use but requiring further treatment other than normal industrial practice before use (i.e. waste recovered by recycling) shall follow the requirements laid down in section 5.2.3 on material recycling.

“Normal industrial practice” can include all steps which a producer would take for a product, such as the material being filtered, washed, or dried; or adding materials necessary for further use; or carrying out quality control. However, treatments usually considered as a recovery operation cannot, in principle, be considered as normal industrial practice in this sense. Some of such processing tasks considered as normal industrial practice can be carried out on the production site of the manufacturer, some on the site of the next user, and some by intermediaries, as long as they also meet the criterion of being ‘produced as an integral part of a production process’ (adopted from the EU’s Guidance on the interpretation of key provisions of Directive 2008/98/EC on waste).

A co-product in contrast is produced as an integral part of a multi-output process where its further use is certain. Typically, co-products directly replace a raw material or fuel without requiring further processing other than normal industry practice. For co-product allocation, multi-output allocation applies (please refer to section 5.1.2). The hierarchy as shown in Figure 9 shall be applied (please refer to Annex B for definitions of the respective criteria).

Residues classified as waste following the hierarchy can also be transformed into recycled feedstock. However, this transformation would require further processing other than normal industry practice (see point 3 in Figure 8), such that the residue would be classified as waste in the first instance. Pre-consumer scrap that is not reintroduced into the same process (i.e., all scrap except run-around scrap) shall be defined as waste unless legal evidence (following legislation of the region where scrap is generated, e.g., legal judgement or legal report from regional waste legislation) exists that classifies the pre-consumer scrap material as co-product.

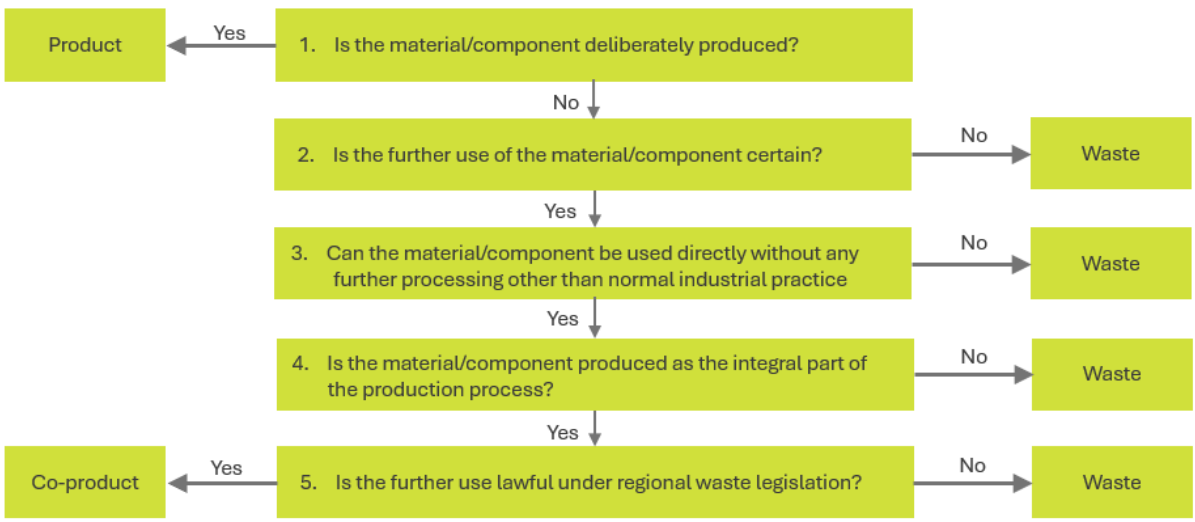


Figure 8. Waste vs. co-product classification hierarchy based on EU Waste Framework Directive

Any emissions arising from the treatment of production waste shall be included in the LCA ("polluter pays principle"). Since the AX boundaries span from cradle-to-gate, this production waste treatment refers to the production life cycle stage only. Waste can be generated during different stages of a product's life cycle (cradle-to-gate), including:

- Resource extraction, raw material sourcing,
- Production of materials, semi-finished products,
- Production of aircraft parts and components,
- Logistics to supplier gate (including internal logistics).

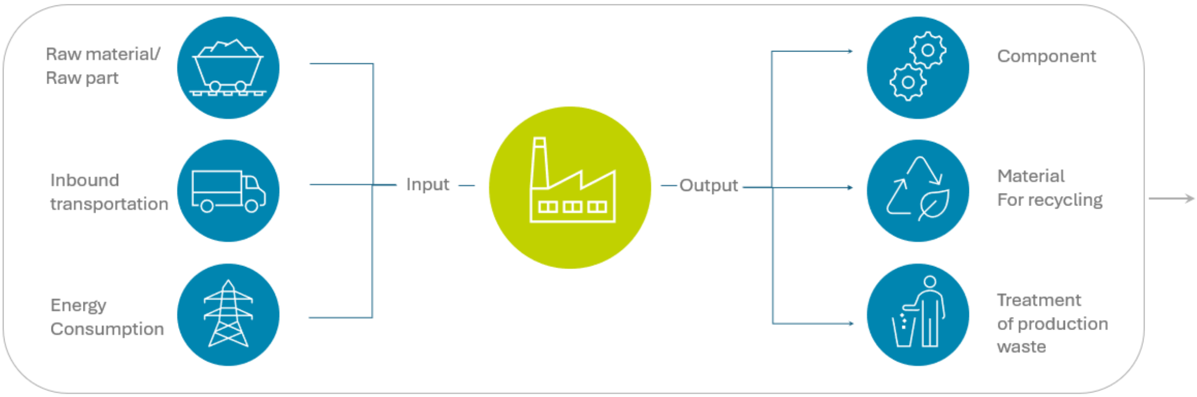


Figure 9. Waste generation during different stages of a product's life cycle

All auxiliaries and energy inputs and waste outputs shall be fully considered in the calculation of the LCA. Cut-off rules as described in section 4.3.1 shall be applied.

The company generating waste is responsible for treatment until final disposal (for example, incineration or landfill, "polluter pays principle"). If additional processes follow the end-of-waste state, then these are attributed to the company using the recycled or reused material flow as a secondary material. The impact of preparatory steps and supporting activities such as collection, transportation, sorting, dismantling, or shredding shall be added to the inventory results of the product system generating the waste. The impact of the process of treating waste with energy recovery (e.g., incineration) shall be added to the inventory results of the product system that generated the waste treated in the process. The energy recovered from waste-to-energy process shall be treated as free of burdens. Production processes may also generate material scrap that is recycled. In this case, please see Section 5.2.3 Accounting for recycling.

Emissions shall be calculated using primary data regarding the type of waste, its composition and type of waste treatment activity. Depending on the type of waste treatment (for example landfill or incineration), companies may use waste treatment emission factors based on internal primary data. If no primary emission factors are available, emission factors derived from accepted secondary databases can be employed (section 7.2). If companies do not have access to primary data from third-party waste treatment facilities, they should estimate waste treatment emissions based on primary data on the waste type and composition and specific emission factors according to the quantity and type of waste treatment and final disposal (landfill, incineration).

5.2.3 Accounting for recycling

Recycling plays a crucial role in enabling a circular economy and reaching climate protection goals. In particular, recycling of currently unused or inefficiently used material streams is key to reducing primary material use as well as environmental burdens related to current waste treatment. The environmental burden of the recycling process needs to be distributed between the systems receiving and providing secondary material.

In principle, ISO 14044 applies the same allocation for recycling cases hierarchy for multi-output systems. However, specific assessment approaches for recycling are described in ISO 14044: avoided burden for the primary production route and cut-off. Avoided burden of the primary production route usually incentivizes the provision of material for recycling at the end-of-life and, thus should only be applied if these incentives lead to overall emission reductions. However, if environmental incentives can lead to overall emission reductions, this highly depends on the market situation and requires a detailed analysis. Consequently, the cut-off approach in accordance with the recommendations of the IAEG LCA framework shall be applied due to the following reasons:

- Ease of use in an AX network
- Avoidance of double counting
- Higher comparability of LCA/ PCFs within AX

The product system generating material for recycling follows a cut-off approach in a cradle-to-gate scope. Preparatory steps for recycling shall generally be allocated to the waste / recyclable material receiving system (i.e., the product system using the (to be) recycled material). This deviation from the polluter pays principle (as required for waste-to-energy, incineration, or disposal emissions) is a pragmatic exemption as following the polluter pays principle in this context would require defining material- and component-specific system boundaries. Other than emissions from the respective preparatory steps and recycling treatment emissions, to be recycled, to be re-used, or to be re-manufactured materials enter the product system using recycled material burden-free. For pre-consumer scrap, preparatory steps owned by the company generating waste shall be accounted for by the producer of waste (might be insignificant; cut-off rules apply).

AX acknowledges the environmental steering effects of selecting allocation approaches and hence may prescribe other allocation approaches to specific materials and regions in the future. The allocation methods described in sector-specific guidelines may serve as the basis for deciding if other allocation methods are prescribed.

5.2.4 Accounting for emissions from electricity

For each process step within the AX boundaries that requires electricity, companies must determine which emissions were emitted by this specific energy use. Mainly, GHGs are emitted through electricity generation, which is why the focus is particularly on the impact category climate change. All (GHG) emissions resulting from the use of the required electricity during the production process (cradle-to-gate) shall be included in the PCF and LCA. To calculate the share of electricity consumption in the PCF, source-specific emission factors shall be used. Depending on the type of electricity generation, different amounts of GHGs are emitted. The factors used shall take into account upstream emissions (e.g., the mining and transport of fuel to the electricity plant or the growing and processing of biomass for use as an energy source), emissions during the generation of electricity (e.g., combustion of fossil fuels) including losses during transmission and distribution and downstream emissions (e.g., the treatment of waste arising from the electricity plants).

In connection with the rules defined for accounting for waste treatment (section 5.3.2), energy recovered from the waste-to-energy process shall be treated as free of burdens.

5.2.4.1 Electricity from a directly and dedicated connected generator

If electricity is produced on site with a direct connection to the power source (e.g., photovoltaic plant on the roof, wind park beside the production facility, own fossil power plant) or a direct connection to a power source operated by a power supplier, the amount of electricity consumed by this power source and the related emission factor shall be used if no contractual instruments have been sold to a third party (primary data). Otherwise, the local- or country-specific residual grid mix (secondary data) shall be used, as recommended by IAEG LCA Aerospace Framework. In most recognized LCA databases there are details and coverage in the grid mix to recommend their usage, if the region of production is within the coverage. As verification of using electricity from the company's own facilities, proof of installation of the company's own generation technology as well as a meter reading shall be available. The amount of electricity and the period of the meter reading shall be equal to the amount of electricity required and the respective period. In addition, the meter reading should be confirmed by a third party to prove that the specified generation technology, the respective period and the amount of electricity generated are in fact as stated. The infrastructure emissions shall be reported for the specific generator type (e.g. onshore wind turbine, solar panel, etc.) reflecting the specific emissions from the construction and decommissioning of the generator as well as the respective local capacity factor and lifetime definitions.

5.2.4.2 Electricity (from a power supplier or) via contractual instruments

If electricity is accessed via a contractual instrument, the following electricity mix shall be used:

1. Supplier-specific electricity product shall be used if:

- a tracking system is installed in the region/country.
- the set of minimum criteria to ensure the contractual instruments are reliable is met, i.e., no double counting and no exclusions.

2. Total supplier-specific electricity mix, i.e., the share of electricity supply specific to the supplier, shall be used if the set of minimum criteria is met to ensure the contractual instruments are reliable.

The country-specific residual grid mix (consumption mix) shall be used (such as AIB5 for Europe). Country-specific means the country in which the activity occurs. The regional residual grid mix (consumption mix), e.g., EU+EFTA, or region representative residual grid mix, consumption mix, shall be used. In general, three different reference types can be defined for contractual instruments:

Utility Tariffs
When using an electricity supply contract, electricity is purchased from a supplier via the public grid.

Energy Attribute Certificates (EACs)
EACs should enable renewable energy to be tradable. An EAC is a certificate that proves that one megawatt hour of electricity was generated from renewable energy and transferred into the electricity grid. EACs can be separated from the physical quantity of electricity and therefore traded independently. Depending on the region, different systems are in place for trading EACs. For example, International Renewable Energy Certificates (iRECs) are traded through an international registry as a renewable energy instrument. In contrast, Renewable Energy Certificates (RECs) or Guarantees of Origin (GoOs) are examples of verification instruments in specific regions.

Power Purchase Agreements (PPAs)
A PPA is an electricity supply contract concluded directly between an electricity producer (plant operator) and an electricity consumer. The contract specifies the delivery of a certain amount of electricity over a particular period at an agreed price. In general, the types of PPAs can be differentiated. There are physical PPAs, which can be further subdivided into on-site and off-site, and virtual PPAs. Electricity from PPAs can only be considered an eligible linked with EACs.

The contractual instrument used to calculate the related emission factor shall meet the following minimum criteria:

- It shall convey the information associated with the unit of electricity delivered together with the characteristics of the generator.
- It shall be assured with a unique claim and therefore be the only instruments that carry the environmental attribute claim associated with that quantity of electricity generated.
- It shall be tracked and redeemed, retired or cancelled by or on behalf of the company (e.g., by an audit of contracts, third-party certification, or may be handled automatically through other disclosure registries, systems, or mechanisms).
- It shall refer to the same year to which the contractual instrument is applied. The attribute tracking instrument shall refer to an electricity production asset located in the same regional market (within which an interconnection can be proven).
- If the electricity consumed comes from more than one electricity mix, each mix source shall be used in terms of its proportion in the total kWh consumed. If a certificate of origin covers only a part of the consumed electricity, the residual grid mix shall be used for the uncovered amount.

In addition to the emission factors as shown in the contractual instrument of the electricity, the following emissions shall be taken into account:

- Upstream emissions (e.g., the mining and transport of fuel to the electricity plant, the growing and processing of biomass for use as an energy source or construction and maintenance).
- Downstream emissions (e.g., the treatment of waste arising from the electricity plants).

5.2.5 Homogeneous parts

While some parts in the aerospace supply chain are considered identical and require sampling strategies, there is also the related issue: Products are nearly identical but differ systematically in a single (or very few) aspect(s). This very often leads to environmental impacts that are identical or differ systematically with that aspect. If this applies, products are called homogeneous parts from a homogenous product family. LCA results obtained for homogeneous parts may be used after interpolation as described below regarding the differentiating aspect for further parts of that product family.

To belong to a homogenous product family, the products shall have the following characteristics:

- The same main function.
- The same product standards.
- The same manufacturing technology, processes, and materials.
- The same supply routes.

A homogenous product family can be substantiated if a product parameter (physical characteristic) can be identified that differentiates otherwise identical parts systematically with respect to PCF / emissions and is proven by a sensitivity analysis. PCF / LCA results for homogeneous parts allow for a linear regression with respect to the differentiating parameter that renders a coefficient of determination R2 > 90%. Cut-off rules apply for the calculated emissions. The sample size to prove interpolation quality shall be n > 20.

Emissions for a part from a homogeneous product family shall be calculated by interpolation only. A homogeneous product family may be defined on the basis of an intermediate product if the final product to market is produced by varying add-on parts to the intermediate product or additional process steps, e.g., specific painting processes, additional leak tests or washing processes. For the additions in parts or processes to the intermediate product the respective emission contribution shall be added to the final LCA results (e.g. CO_2e to the total PCF). For the calculation of the primary data share, data does not need to originate from the product system under study, because primary data might relate to a homogeneous part. The proof of a homogeneous product family shall be documented and provided to customers on request. A review of the proof shall be performed after five years at the latest.

5.2.6 Accounting for chain of custody models

Chain of custody is an administrative process by which information about materials is transferred, monitored, and controlled as those materials move through supply chains [ISO 22095:2020]. There are, in principle, five possible chain of custody models, illustrated in Figure 10. Their common objective is to guarantee correct accounting and corroborate a link between ingoing content, e.g., ‘sustainable’, ‘recycled’ or ‘organic’ by harmonized definitions, and the final outgoing product. They differ whether it is a physical or administrative link. Furthermore, they differ in the set of rules for balancing, and the option to keep materials streams segregated or not.[10]

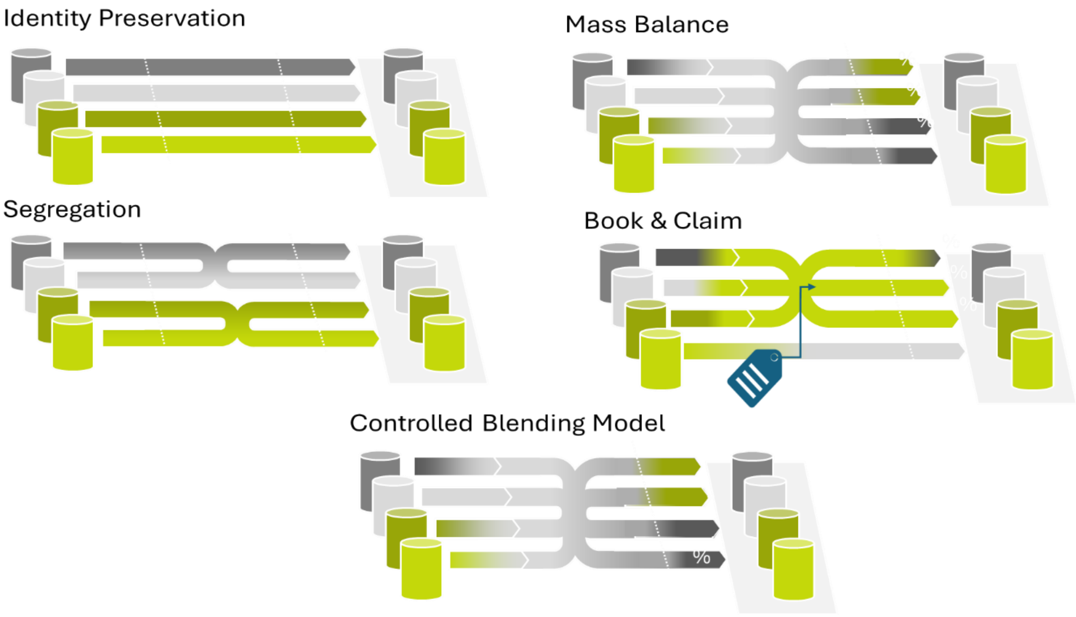


Figure 10. Overview of chain of custody models

The following table was adapted from the above-cited Whitepaper and provides high-level explanations and differentiations for the five chain of custody models:

Table 2. Explanation chain of custody models
[adapted from EMF Whitepaper Table 1, page 11]

Model	Explanation	Example
Identity preservation	It is possible to physically track the product to its desired origin, ensuring unique traceability and physical separation of products from other sources along the supply chain.	Buying food from a single certified producer
Segregation	Consists in the aggregation of volumes of products of identical origin or produced according to the same standards in one stock item.	Buying food from a trader that exclusively handles identically certified supplies.
Mass balance	Considering the output, no physical or chemical difference exists between in-scope and out-of-scope. It involves balancing volume reconciliation to ensure the exact volumes of in and out-of-scope source is maintained along the supply chain. Given that the volume or the ratio of sustainable material integrated is reflected in the product produced and sold to customers. This model requires that a reconciliation period is defined (e.g., a month, a year). Two different allocation methods can be applied within the mass balance model to manage and assign sustainability attributes: the Rolling Average Method and the Credit Method.	Buying a certain percentage of a supply from certified origin. Applies to, e.g., sustainable forestry for wooden materials, recycled, bio-based or renewable materials, organic cotton.

[10] Ellen MacArthur Foundation (2019): Enabling a circular economy for chemicals with the mass balance approach. https://www.iscc-system.org/wp-content/uploads/2022/04/Mass-Balance-White-Paper.pdf

	• In the Rolling Average Method the share of sustainable input is averaged over time, allowing companies to claim a time-weighted average proportion of sustainable content in their outputs across the reconciliation period. • The Credit Method allows companies to accumulate and assign credits for sustainable inputs to specific outputs, meaning that the sustainability attributes are explicitly linked to individual products.	
Book & claim – restricted certificate trading	The certified product/component is disconnected from the certification data but belongs to the same production system or value chain. The certified product evolves in separate flows from the certified supply. Certificates are issued at the beginning of the supply chain by an independent body reflecting the sustainable content of supplies. The intended outcome is that outputs from one supply chain is associated with total claims corresponding to the certified input.	Buying material with renewable / recycled / biobased content. Certificates with guarantee of origin or comparable certifications declaring e.g. recycled, renewable, biobased content. CO_2 capture certificates from a production system controlled by the company, e.g., carbon capture and storage.
Controlled blending	This model allows the blending of certified and non-certified materials under controlled conditions, ensuring that the total amount of certified input is known and managed throughout the process. Unlike mass balance, blending occurs at defined points in the supply chain, and traceability is maintained through robust documentation and verification systems. The aim is to gradually increase the share of certified material while maintaining transparency about the composition of final products.	Producing packaging where a defined proportion of recycled plastic is mixed with virgin material in a controlled production batch. The percentage of recycled content is verified and declared to the customer, ensuring accountability and supporting sustainability goals.

To calculate emissions according to the AX rulebook, all types of models may be taken into account if the requirements of the guiding principles listed below are met and an independent third-party chain of custody verification for the balance of materials is available. The balance between input and output shall be correct.

The mass balance approach helps enable fossil raw materials to be replaced by more sustainable alternative materials (e.g., with recycled content, bio-content). In contrast to a segregated use of alternative raw materials, mass balance enables the use of existing production networks with low or no investments into new process technologies and production facilities. A book and claim model should only be applied as additional information, as it is not consistent with ISO 14040/44. An example of a book and claim model is applied in green electricity markets and receives more attention in other sectors as way to support circular transformation of the industry; therefore, it is accepted as a solution. There will be a regular review by AX to decide about the further necessity.

5.2.6.1 Guiding principles

In implementing chain-of-custody methods, including mass balancing, the following set of guiding principles shall be fulfilled:

1. The use of chain-of-custody approaches shall achieve significant changes and an effective transition towards a more circular, more bio-based and lower emissions production in complex value chains.

2. The choice and implementation of chain-of-custody approaches and models shall be transparent, clear and credible – abiding by relevant standards such as ISO and CEN. Such credibility can also be achieved but is not limited to accepted third-party certification schemes, e.g., ISCC PLUS and RSB. Note: Certification schemes are not yet available in all sectors.
3. Labels and claims referring to chain-of-custody controlled specified characteristics and used on products shall fulfill the following requirements:
    - Description of the chain-of-custody approaches and models.
    - Accurate and appropriate implementation of the chain-of-custody model.
    - Compliant with existing standards and regulations.
    - Non-misleading.

   If the "specified characteristic" content in products cannot be measured and verified, labels and claims shall mention this. For example, this often applies to mass balancing (e.g., chemically recycled content in plastics).
4. No double counting: A reliable accounting system shall be installed at each operating site to ensure that the claimed volume on the output side exactly matches the actual volume on the input side within the declared time and regional scope.
5. The operating sites in the spatial boundaries for mass balancing are under the operational control of the same company/corporate group/joint venture.

Additional requirements for a mass balance chain of custody approach:

6. It shall be technically possible according to standard industry practice to produce a mass-balanced product from an alternative feedstock. Share of mass-balanced material can be technically lower than the attributed share.
7. Only additional measures relative to the PCF / emissions of the residual product shall be considered. The residual product is the product without reduction measures used in mass balance within the respective reporting year.
8. Physical traceability of the material in the supply chain: By default, it shall be possible for portions of the material to be physically present in the product.
9. Applied emissions factors for the mass-balance system boundaries shall be product and process specific.

6 Impact categories

Based on the IAEG LCA Framework document, five additional impact categories (in addition to climate change) are particularly relevant for the aviation industry:

- Climate Change (PCF)
- Resource Use (Fossils)
- Resource Use (Minerals and Metals)
- Photochemical Ozone Formation (Summer Smog)
- Acidification
- Particulate matter

This chapter consolidates AX rules for impact categories to support consistent, comparable, and traceable reporting across aerospace supply chains. The following approach is partially based on *The Environmental Sustainability Guideline for the Chemical Industry* published by Chem-X. The impact category Climate Change (PCF) is mainly based on the CX PCF Rulebook Version 4 (detailed description in chapter 6.1). All further impact categories (detailed description chapter 6.2-6.6) apply the Environmental Footprint (EF) methodology as the underlying characterization framework, ensuring alignment with EU-level LCA standards across all indicators. In AX v2.0, climate change is mandatory during the transition period, while other categories may be reported where relevant; subsequent releases may expand the mandatory set. Each category method, indicator/unit, boundary, and any conventions are defined within its own subsection, and results are reported per declared unit.

6.1 Climate Change (PCF)

Relevance for the aviation industry

In AX, the PCF is the standard product level dataset for supplier to customer exchange and aircraft level aggregation. During the transition period, climate change is the mandatory category, and PCF is calculated using the single impact category GWP100 with IPCC AR6 characterization factors applied to the full GHG list; results are expressed in kg CO_2e and are directly comparable. The cradle to gate scope and reporting per declared unit enable engineering and operation teams to pinpoint hotspots across materials and intermediates, energy and process heat, process gases/fugitives, packaging, and inbound/internal logistics, so reduction efforts focus on levers within the AX boundary.

This section pairs the GWP100 basis with AX required data fields (declared unit, period and geography, database/version, two totals – T1 including biogenic CO_2 uptake and T2 excluding, component positions A–H, biogenic and total carbon content, and the quality indicators PDS/DQR). This supports multisector suppliers in sharing PCF data consistently while remaining grounded in AX's data exchange model.

Impact category description

The PCF is the sum of GHG emissions and removals in a product system, expressed as CO_2-equivalents-, based on an LCA using the single impact category climate change (GWP100).[11]

[11] ISO 14067:2018, *Greenhouse gases – Carbon footprint of products*, https://www.iso.org/standard/71206.html.

[12] The calculation shall use IPCC 2021 GWP total (incl./excl. biog. CO2) and IPCC AR6 characterization factors (including carbon -cycle/chemistry feedbacks) for all required GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3, HFEs, PFPEs, CFCs, HCFCs, etc.). Where a gas is not listed in AR6 Chapter 7 Table 7.15, the factor shall be taken from AR6 Supplementary Materials[13] Table 7.SM.7. Upon publication of a new IPCC Assessment Report, the factors shall be updated within two (2) years; if secondary data uses older factors during the transition, this shall be clearly stated and datasets using the latest factors shall be prioritized.

The following section provides additional technical details on biogenic accounting and component reporting to support practitioners in applying the methodology correctly.

Biogenic accounting and the two mandatory totals (transition period):

- Characterization: Biogenic CO_2 uptake shall be characterized at −1 kg CO_2e per kg CO_2; biogenic CO_2 emissions at +1 kg CO_2e per kg CO_2. Biogenic non-CO_2 GHGs (e.g., CH_4) shall use AR6 factors. The product's biogenic carbon content and total carbon content shall be reported separately. Removals in the PCF shall not include measures not related to the production system (i.e., carbon offsets).
- Dual totals: Report two totals during the transition period:
  - T1 – GWP total including biogenic CO_2 uptake (−), and
  - T2 – GWP total excluding biogenic CO_2 uptake.

T1 shall be used for Primary Data Share (PDS), Data Quality Rating (DQR) and verification shares.

To ensure transparency and consistent aggregation, report (as applicable) the following components (as defined in Figure 11 and Table 3); totals are built from these positions:

- A – GWP fossil: fossil/process emissions including stationary/mobile combustion and fugitives.
- C – GWP biogenic (non-CO_2) emissions (e.g., CH_4 from biomass burning, digestion, composting).
- D – GWP biogenic CO_2 uptake (−) bound in the product, provided this uptake is documented.
- E – GWP from direct land-use change (LUC).
- F – Land management CO_2 emissions and G – land management CO_2 removals (−) (net carbon stock changes within the same land category).
- H – Upstream aviation emissions in distribution stages (where relevant).

Formulas: T1 = A + C + D (−) + E + F + G (−) + H; T2 = A + C + E + F + G (−) + H.

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[12] Greenhouse Gas Protocol. (2013). *Required gases and global warming potential (GWP) values*. https://ghgprotocol.org/sites/default/files/standards_supporting/Required_gases_and_GWP_values_0.pdf

[13] https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07_SM.pdf

Table 3. Explanation of the contributing factors of the biogenic uptake

Emission	Conditional	Description
GWP total incl. biogenic CO_2 uptake	Shall	Position T1 = A+C+D (negative contribution) +E+F+G (negative contribution) +H. Letters refer to individual emission categories below. This also refers to the -1/+1 Approach. "GWP total incl. biogenic uptake" may be set equal to "GWP total excl. biogenic uptake" if the product has no or a neglectable biogenic carbon content. General cut-off criteria apply as criteria for negligibility.
GWP total excl. biogenic uptake	Shall	Position T2 = A+C+E+F+G (negative contribution) +H. Letters refer to individual emission categories below. This also refers to the 0/0 Approach.
GWP fossil	Should	Position A: includes all fossil emissions, including industrial processes, stationary/mobile combustion and fugitive emissions. This position includes the fossil emissions associated to land management (A1: "GWP fossil land management") which is not part of the AX LCA data model but of PACT and TFS.
GWP biogenic emissions other than CO_2	Should	Position C: non-CO2 biogenic emissions related to agricultural activities. It encompasses emissions as described in PACT v3.0: CH4 emissions from livestock and manure; CH4 emissions from biomass burning and fires; CH4 emissions from rice production; CH4 emissions from transformation and degradation (e.g., combustion, digestion, composting, landfilling). It must be noted that N2O from land management activities are not included in this position and are reported in position A and A1 (as a detail).
GWP biogenic CO_2- uptake (biogenic CO_2 contained in the product)	Should	Position D (negative contribution): The CO2 which was absorbed from the atmosphere during the growth period of the biomass and of which the C is now bound in the product as biogenic carbon content.
GWP land use change (LUC, excluding iLUC)	Should	Position E: Emissions from LUC constitute a release of GHG emissions due to a change in land use from one land use category or subcategory to another, such as primary forest to agricultural land, or peat land (type of wetland) to cropland. This position encompasses dLUC (direct land use change) emissions. If that data is not available, companies should account for LUC using statistical land-use change (sLUC) emissions. iLUC emissions are excluded. Refer to PACT v3.0 for details.
GWP Land Management CO_2 Emissions	Should	Position F: carbon stock losses occurring within the same land use category or subcategory due to agricultural practices such as tillage, field preparations, pruning and harvest. Land Management CO2 emissions measures biogenic CO2 emissions from a net loss in carbon stock within one land use category or subcategory. This includes impact on the land-carbon pools, including above and below-ground biomass, dead organic matter, and soil carbon pools. If the carbon stock increases within the same land use category and the conditions to report removals are met, this may be calculated as a Land management CO2 removal (position G). Refer to PACT v3.0 for details.

GWP Land Management CO_2 Removals	Should	Position G (negative contribution): Land management removals are net CO2 removals resulting from net increases to carbon stored in land-based carbon pools (biomass, dead organic matter and soil carbon pools) due to ongoing land management practices. This extra net carbon stock is gained over the crop rotation or crop cultivation cycle (e.g., multiple years for perennial crops and multiple years in a rotation that includes annual crops). Refer to PACT v3.0 for details.
GWP Aviation emissions (upstream)	Should	Position H: Aviation emissions which have occurred in distribution stages upstream.

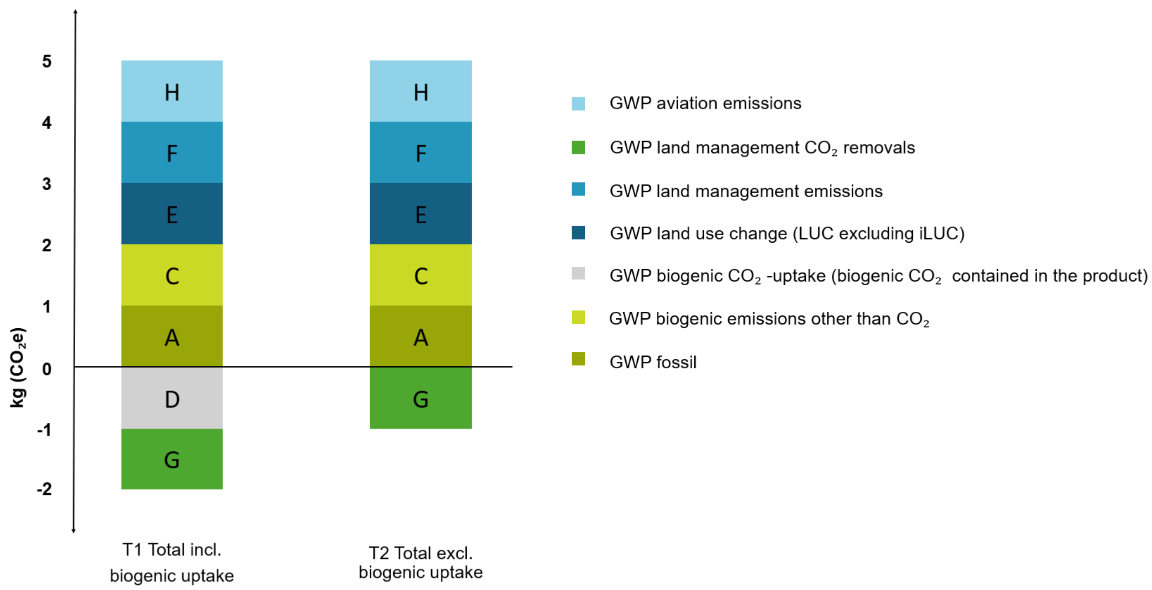

Figure 11. Overview of the specific components of the PCF

Regulatory relevance

Declaration of GHG emissions is mandated by multiple mutually reinforcing regulations and guidelines. Regulation (EU) 2021/1119 ("European Climate Law") makes the EU climate framework legally binding by enforcing companies to set and track climate targets. EU ETS for aviation, which prices CO_2 from flights within/linked to Europe and sets monitoring/reporting obligations. The Carbon Border Adjustment Mechanism (CBAM) requires importers of certain carbon-intensive goods to declare embedded emissions, effectively extending carbon accountability to imports. Corporate transparency rules such as Corporate Sustainability Reporting Directive (CSRD) require in-scope companies to disclose climate information including GHG emissions (Scopes 1–3 where relevant), creating strong downstream pressure for supplier and product emissions data.

6.2 Resource use (Fossils)

Relevance for the aviation industry

The aerospace manufacturing industry relies heavily on fossil resources, which play a crucial role as feedstocks, process energy sources, and chemical precursors in the production of aircraft materials and components. Fossil-based inputs are deeply embedded in the upstream supply chain, long before aircraft enter service.

Dual role of fossil inputs:

- Energy for intensive processes: forming, curing, machining, surface treatment.
- Chemical backbone for materials: polymers, resins, adhesives, sealants, high-performance composites, insulation materials, and engineered plastics.

This dual role mirrors other industrial sectors where fossil resources provide both the energy and the chemical backbone necessary for modern material production.

The aerospace industry, like other energy-intensive manufacturing sectors, faces structural challenges in reducing fossil resource use. High-performance materials—such as carbon-fiber-reinforced polymers (CFRP), thermoplastic composites, epoxy systems, engineered elastomers, and specialty coatings—often originate from petrochemical intermediates, which currently lack cost-competitive non-fossil substitutes at scale.

Fossil resources remain central to many upstream processes from producing energy-intensive composite precursors to synthesizing engineered polymers. As a result, evaluating “Resource Use, fossil” in cradle-to-gate environmental assessments is a key step toward improving sustainability in aircraft manufacturing. Responsible use of fossil feedstocks ensures that high-performance materials can continue to be produced, while supporting long-term resource conservation for future applications where no viable substitutes exist.

Description of the impact category

Resource use fossil as an environmental impact category reflects the potential depletion of fossil resources due to their extraction and use, but it is not a physical property of the product itself. For fossil-based products, the “Resource use fossil” value typically exceeds the product’s LHV, because it accounts not only for the fossil content embedded in the product but also for the upstream fossil resource consumption throughout the pre-chain. However, due to allocation rules applied in multi-output processes, it is possible that the calculated Resource use fossil for a specific product is lower than its LHV. This does not imply an error but reflects the chosen allocation method, which shall be applied uniformly across all impact categories. In such cases, besides Resource use fossil also the LHV can be reported. A comment should be included to explain why the Resource Use Fossil is lower than the LHV, ensuring transparency and enabling accurate modelling in downstream processes. Additionally, for products with partial or full biogenic content, the Resource use fossil may be significantly lower than the LHV, since biogenic inputs do not contribute to fossil resource depletion.

Regulatory relevance

European regulatory frameworks – such as the European Green Deal and the Renewable Energy Directive intensify pressure on industrial supply chains to shift from fossil resources toward renewable and circular alternatives. Further, aviation specific regulations such as ReFuelEU avaition mandates reductions in fossil-derived aviation fuel. SAE AS9100 and aerospace sustainability frameworks increasingly require reporting on polymer and composite fossil feedstock and fossil-based adhesives, foams, lighting components, and wiring. These initiatives aim to reduce fossil dependency, expand renewable energy use in manufacturing, and stimulate innovation in low-carbon material production.

6.3 Resource use (Minerals and Metals)

Relevance for the aviation industry

Aerospace designs require aluminum, titanium, nickel-based superalloys, copper, rare earth elements, and increasingly critical raw materials like scandium, neodymium, dysprosium, and cobalt for advanced alloys, electronics, sensors, and high-efficiency electric systems. These materials have limited global reserves and are concentrated in a few regions, making their extraction linked to potential scarcity risks and supply-chain vulnerability. These materials have limited global reserves and are concentrated in a few regions, making their extraction linked to potential scarcity risks and supply-chain vulnerability. By evaluating mineral and metal resource use, aerospace companies can identify opportunities for lightweighting, improved material efficiency, recycling of high-value alloys, design for circularity, and substitution with more abundant materials or alternatively renewable materials.

Description of the impact category

This impact category has the same underlying basic idea as the impact category resource use, fossils. The focus here is to quantify the extraction of resources today will force future generations to extract lower concentration or lower value resources. It reflects how mining and processing these materials deplete finite geological stocks, require significant energy inputs, and can lead to long-term scarcity risks as global demand increases. The amount of materials contributing to resource depletion are converted into equivalents of kilograms of antimony (kg Sb eq).

Regulatory relevance

EU regulations such as Critical Raw Materials Act (CRMA) are the central regulation governing metals and minerals supply, and this pushes for the reduction of primary critical metals; mandates circularity. RESourceEU focuses on rare earth magnets & raw materials relevant to aerospace and mandates the increase of recycled content availability and keeping scrap in the EU.

6.4 Photochemical Ozone Formation

Relevance for the aviation industry

Photochemical ozone formation is a critical impact category for the aerospace industry, primarily driven by emissions from high-temperature combustion and the extensive use of chemicals in manufacturing and maintenance. Impact across the life cycle is significant, spanning from fuel production and aircraft operations to specialized surface treatments and coating processes.

The industry's contribution to photochemical ozone formation is primarily driven by:

- Nitrogen oxides (NO_x) released from engine operation during LTO and cruise as well as engine testing. In addition, CO and NMVOCs are emitted due to incomplete fuel combustion.
- Non-methane volatile organic compounds (NMVOCs) arising from solvent-heavy processes during manufacturing and MRO, for example
  - Production of carbon-fibre reinforced polymers and curing of resins (off gassing)
  - Application of adhesives, sealants or surface coatings and paintings
  - Cleaning and degreasing operations
  - Stripping of old coatings
- Upstream fuel supply chains, specifically fugitive emissions and combustion during the refining and distribution of conventional and alternative aviation fuels
- Energy intensive production of high-performance materials for metallic and composite structural components

From a sector perspective, this category is especially relevant because:

- Airport Local Air Quality: Ground-level ozone formation is a primary concern for airport operators and local authorities, as it directly impacts the health of personnel and surrounding communities.
- Process Chemistry: Aerospace manufacturing relies on high-performance solvents and precursors (alkenes, aromatics, and aldehydes) that possess high ozone formation potential.
- Regulatory Scrutiny: Increasingly stringent limits on VOCs and NO_x at industrial sites and airports make this a vital metric.
- Technology Trade-offs: It serves as a necessary check to ensure that, for example, new engine designs optimized for CO_2 reduction do not inadvertently increase NO_x emissions or that bio-based cleaners do not introduce more reactive VOCs.

Description of the impact category

The impact category Photochemical Ozone Formation accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of Volatile Organic Compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) and sunlight. It is thus not the VOCs per se which cause environmental problems associated with photochemical ozone formation, but the products of their transformation in the troposphere. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials through reaction with organic materials.

The main sources of anthropogenic NMVOC emissions are use of solvents, combustion (in particular from road transport and other mobile sources and machinery) as well as fugitive emissions from fuels, and industrial processes[14,15], while the majority of CO and NOx emissions stems from combustion processes in transport, energy- and waste incineration systems[16].

The photochemical formation of ozone in the troposphere from emissions of VOCs and NOx follows rather complex reaction schemes that depend on the nature of the specific organic compounds emitted from anthropogenic and natural resources. Regional levels of concentration and meteorological conditions influence the process.

Photochemical ozone formation shall be calculated using the EF LCIA method. In EF 3.1, the impact is quantified using the LOTOS-EUROS model. This model accounts for the complex atmospheric chemistry where precursors react at different rates depending on the local concentration of other pollutants. The indicator for this impact is the increase in the concentration of ozone in the troposphere. The unit of measure for this indicator is kg NMVOC eq.

Regulatory relevance

Governments and environmental agencies have established strict regulations to control VOC emissions and reduce ground level ozone. In the European Union, the Industrial Emissions Directive (2010/75/EU) sets limit values for VOCs, while the EU Ambient Air Quality Directive (2008/50/EC), currently being updated to align with 2021 WHO recommendations (Directive 2024/2881), sets binding limits for pollutants linked to ground-level ozone formation. Internationally, the UNECE Gothenburg Protocol establishes national emission ceilings for NO_x and VOCs to abate ground-level ozone. In the United States, the Clean Air Act and National Ambient Air Quality Standards (NAAQS) regulate ozone precursors, while China's Air Pollution Prevention and Control Law mandates strict VOC reductions and the adoption of low-VOC materials in industrial sectors.

6.5 Acidification

Relevance for the aviation industry

Acidification is a material and operationally relevant impact category for aerospace systems due to emissions arising across the full life cycle of aircraft products, including raw material extraction, material processing, manufacturing, fuel production, and aircraft operation.

Dolganova et al. 2022[17] demonstrate that acidifying emissions are primarily driven by:

- Nitrogen oxides (NO_x) and sulfur oxides (SO_x) released during fuel combustion,
- Energy-intensive metal production (notably aluminum, titanium, and nickel alloys),

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[14] Laurent, Alexis; Hauschild, Michael Z. Impacts of NMVOC emissions on human health in European countries for 2000–2010: Use of sector-specific substance profiles, Atmospheric Environment, Volume 85, 2014, Pages 247-255, https://doi.org/10.1016/j.atmosenv.2013.11.060

[15] Donzelli, G.; Suarez-Varela, M.M. Tropospheric Ozone: A Critical Review of the Literature on Emissions, Exposure, and Health Effects. *Atmosphere* 2024, *15*, 779. https://doi.org/10.3390/atmos15070779

[16] Hauschild, M. Z., Rosenbaum, R. K., & Olsen, S. I. (Eds.). (2018). Life Cycle Assessment – Theory and Practice. Springer. https://doi.org/10.1007/978-3-319-56475-3

[17] Dolganova, I., Bach, V., Rödl, A. et al. Assessment of Critical Resource Use in Aircraft Manufacturing. Circ.Econ.Sust. 2, 1193–1212 (2022). https://doi.org/10.1007/s43615-022-00157-x

- Upstream electricity generation, particularly where fossil-based energy mixes are used.

From a sector perspective, acidification is especially relevant because:

- Aircraft operations and airport environments concentrate emissions regionally, amplifying local ecosystem sensitivity.
- Aerospace supply chains rely heavily on metals whose production stages are known acidification hotspots.
- Regulatory pressure on air pollutants (NO_x, SO_2, NH_3) is increasing at both airport and industrial levels, making acidification an important complementary indicator to climate change.

Assessing acidification ensures that decarbonization strategies (e.g. fuel switching or lightweighting) do not unintentionally shift environmental burdens toward soil, freshwater, and terrestrial ecosystems.

Description of the Impact Category

The acidification impact category describes the potential of emissions to increase acidity in soils, freshwater systems, and vegetation. Acidifying substances are released into the air and transported over short to medium distances. Once deposited, they alter natural pH balances, reducing soil fertility, harming forests, and acidifying lakes and rivers. They are expressed as a single aggregated indicator, enabling comparability across products and suppliers.

For aerospace LCAs, the most relevant contributors typically include:

- Nitrogen oxides from aircraft engines and combustion processes,
- Sulfur dioxide from fuel supply chains and energy generation,
- Ammonia emissions from upstream industrial activities.

Acidification results are used to

- Identify critical stages in the life cycle where emission controls are most effective,
- Support technology choices for engines, fuels, and materials,
- Inform of trade-off decisions between climate, air quality, and ecosystem protection.

Acidification shall be calculated using the EF LCIA method for acidification using the most updated version, currently EF3.1. The EF method, developed by the European Commission, provides a comprehensive framework for evaluating the environmental performance of products throughout their life cycle. The method uses specific Characterization Factors to translate emissions into potential acidification impacts, considering various substances such as SO_2, NOx, and NH_3.

Regulatory relevance

There are no regulations targeting acidification directly, instead, it is addressed through broader air-pollution frameworks such as the EU NEC Directive (2016/2284/EU), which sets binding emission reduction commitments for NO_x, SO_2, NH_3, NMVOCs, and $PM_{2.5}$ for 2020–2029 and 2030 onwards, in line with the Gothenburg Protocol and the EU Zero Pollution Action Plan. Complementary legislation, including the revised Industrial Emissions Directive and the

Industrial Emissions Portal Regulation, strengthens reporting, transparency, and emission controls from industrial installations, with the objective of substantially reducing key air pollutants by 2050. In the United States, similar objectives are pursued under the Clean Air Act, notably through the Acid Rain Program, which mandates significant reductions of SO_2 and NO_x emissions from major sources.

6.6 Particulate matter

Relevance for the aviation industry

Particulate matter (PM) is a high-priority impact category for aerospace due to its strong links to human health, air quality, and atmospheric effects, particularly in and around airports.

The aerospace case study highlights particulate matter relevance in three key areas:

- Aircraft operations, especially during landing, take-off, and taxiing,
- Airport-adjacent communities, where population exposure is concentrated,
- Upstream energy and material production, where fine particles are emitted during combustion and industrial processing.

Unlike some global environmental impacts, particulate matter is:

- Highly localized, making it especially relevant for airport operators, regulators, and affected communities,
- Directly associated with regulatory air quality limits and public acceptance of aviation activities,
- Increasingly scrutinized alongside NO_x as part of holistic air quality management strategies.

In addition, particulate matter plays a role in cloud formation and atmospheric processes, linking local air quality effects with broader climate interactions.

Description of the Impact Category

The particulate matter impact category quantifies emissions of very small airborne particles that can be inhaled and penetrate deep into the lungs. It focuses on fine and ultrafine particles, which are most harmful to health and considers both direct particle emissions and particles formed indirectly from gaseous precursors.

The particulate matter impact category aggregates emissions into a single, understandable indicator and enables comparison across technologies, fuels, and supply chain configurations.

For aerospace systems, particulate matter emissions typically arise from:

- Jet fuel combustion in aircraft engines,
- Auxiliary power units and ground support equipment,
- Electricity and heat generation used in manufacturing and material processing.

The results support:

- Evaluation of operational measures to reduce local air pollution,
- Comparison of propulsion and fuel options beyond climate impacts alone,

- Transparent communication with regulators and communities affected by aviation activities.

Particulate matter shall be calculated using the EF LCIA method for particulate matter formation, applying the most up-to-date version, currently EF 3.1. The EF method, developed by the European Commission, provides a harmonized and scientifically robust framework for assessing the environmental performance of products across their life cycle. For particulate matter, the method applies dedicated characterization factors to translate relevant emissions into potential impacts on human health, accounting for both primary particulate emissions and secondary particle formation from precursor substances such as NO_x, SO_2, and NH_3.

Regulatory relevance

Particulate matter is a highly regulated air pollutant due to its direct impacts on human health and ecosystems and is addressed through multiple binding air-quality frameworks rather than stand-alone particulate-specific legislation. In the EU, particulate matter ($PM_{2.5}$ and PM_{10}) is covered by the National Emission Reduction Commitments (NEC) Directive (2016/2284/EU), the Ambient Air Quality Directives, and the Zero Pollution Action Plan, which set reduction targets and limit values to significantly lower premature deaths and ecosystem damage by 2030 and beyond. These requirements are reinforced by the revised Industrial Emissions Directive and associated reporting obligations, while in the United States particulate matter is regulated under the Clean Air Act, with National Ambient Air Quality Standards (NAAQS) defining enforceable limits for $PM_{2.5}$ and PM_{10}.

7 Data sources for inventory

7.1 Primary data

Primary data refers to quantified values for a process or activity that are obtained either through direct measurement or calculations based on such measurements. It is important to maximize the proportion of primary data used and to ensure high data quality for both primary and secondary data sources.

Primary data encompasses both primary activity data – such as technical flows – and primary emission factors, which represent e.g. the carbon footprint of a specific activity in terms of kg CO_2eq per unit (see Table 4). Therefore, if material consumption is measured but paired with a secondary emission factor, this does not qualify as primary data (refer to section 8.2.4). Primary data can be collected via methods such as meter readings, purchase documentation, utility invoices, engineering calculations, direct monitoring, material or product balances, stoichiometric analysis, or other approaches that yield process-specific information from the company's value chain. In practice, a single calculation may incorporate both primary and secondary data, with the proportion of primary data indicated by the primary data share. For instance, when estimating emissions from electricity use, primary activity data (e.g., measured kWh consumption) might be combined with a secondary emission factor (e.g., national average GHG intensity per kWh) from official inventories.

Table 4. Possible variances of primary and secondary data

<table>
<tr><th>Approach</th><th colspan="4">Direct emission measurement</th></tr>
<tr><td>Primary data, if</td><td colspan="4">Source of emission is within company boundaries and is measured</td></tr>
<tr><th rowspan="2">Approach</th><th colspan="2">Activity data source</th><th colspan="2">Emission factor source</th></tr>
<tr><th>Energy</th><th>Material</th><th>Energy</th><th>Material</th></tr>
<tr><td>Primary data, if</td><td colspan="2">Consumption measured (primary)</td><td>For on-site production Emission measured (primary)
For supplier-specific electricity
• Primary with guarantee of origin</td><td>Measured and reported as a share by supplier</td></tr>
<tr><td>Secondary data, if</td><td colspan="2">Consumption/production measured (primary)</td><td colspan="2">Secondary databases, data proxy</td></tr>
</table>

Data may require mathematical processing—such as scaling or aggregation—to align it with the declared unit or the process' reference flow (refer to Section 5.1.2). Mathematical modeling can be applied to estimate missing values, while data aggregation might be necessary to smooth out anomalies caused by updates, maintenance shutdowns, or other unusual operating conditions.

If product-specific measurements or calculations for activity data or emission factors are unavailable, it is necessary to use the best available site-specific or even company-level data. Such data may encompass emissions beyond those directly associated with production, for example, those arising from research and development activities.

7.2 Secondary data

AX aims to base its LCA calculations primarily on primary data (especially for activity data), therefore a transition period is required. During this interim phase, secondary data must be used to maintain continuity in the LCA data exchange throughout the entire supply chain.

When secondary data is used, several key requirements should be met:

Secondary data should be applied conservatively to ensure that LCA results are not underestimated compared to those based on primary data.

The selection of secondary data should follow representativeness criteria (see Section 8.2.5) to minimize errors in the LCA. The effort to find the most accurate data should be balanced with practical considerations.

All AX members, regardless of their size, resources, or LCA expertise, shall have access to secondary data.

In order to ensure an AX specific data provision, the following consecutives approaches shall be addressed:

- Definition of AX prescriptive secondary data.
- Definition of a whitelist of data sources.

Combinations of the approaches are also feasible.

To meet the above-mentioned requirements in the future, the first option is clearly the superior approach. By prescribing the use of specific secondary data with adequate precision and following a conservative approach, comparability of results and avoiding underestimation of LCA results can be ensured. Prescribed data sources guarantee that all AX members use the same emission intensities. Equal access to data must therefore be ensured. AX-provided datasets would also eliminate the need for individual data quality ratings. To prevent arbitrary use of universal databases, clear rules are needed to define which approximations are acceptable under AX guidelines. At the moment no AX prescriptive secondary data exists but would be desirable for the aerospace industry. A pragmatic solution with the support of various associations seems to be the most viable way forward.

In alignment with IAEG LCA Aerospace Framework, AX recommends using the following databases as a whitelist for LCA data sources:

- Sphera: Renowned for its extensive LCA databases, Sphera provides detailed data on materials and processes relevant to various industries, including aerospace.
- Ecoinvent: One of the most comprehensive LCA databases available, Ecoinvent offers high-quality data on a wide range of materials and processes, including those specific to aerospace.
- NASA Open Data Portal: This portal provides access to a vast array of datasets related to aerospace and other scientific fields.
- Federal Aviation Administration (FAA) Data & Statistics: Offers data on various aspects of aviation, including operational metrics and environmental impacts.

- USC Aerospace Database: Includes records from periodicals, conference papers, trade journals, and technical reports, covering all aspects of applied research in aerospace.

In these databases there are still gaps, especially for materials. IAEG WG12 is addressing these gaps and will provide further recommendations to improve the existing databases. AX recommends following the most recent IAEG LCA Aerospace Framework version.

If none of these sources provide the necessary data, other sources may be used to fill gaps, e.g. data from scientific sources. If no data is available, proxy data can be used, but its use must be documented and made transparent to auditors and data recipients (see Section 8).

When using secondary data as emission factors, the following quality criteria must be met:

- **Temporal representativeness:** The data's reference year should match the assessment period of the activity data.
- **Geographical representativeness**: The data should reflect the most relevant geographic location for the process.
- **Technological representativeness**: The data should be technologically relevant to the process.

8 Required elements for LCA and PCF data exchange

To enhance comparability and consistency, a standardized process for LCA data exchange is essential. Sharing LCA data and the according meta data between stakeholders within the supply chain is a prerequisite for more granular and accurate calculations. Emissions data calculated in line with the AX LCA Rulebook shall be shared in accordance with AX data model (urn:samm:org.w3id.aerospacex.dataproductmodel.lca.reduced:1.0.0) and requirements in section 8.2.

8.1 Data model

The data model contains the most relevant information that companies shall exchange to enable LCA calculation throughout the entire supply chain in accordance with the AX LCA Rulebook. During the transition period, the reduced LCA data model can be used to exchange a reduced data set, especially to enable SMEs to report the most relevant data points. A report on all required details shall be created to document all relevant information.

8.2 Details on the required data elements

8.2.1 Time period

Environmental impacts shall by default be reported averaged over the period of one year (reporting or calendar year) to avoid seasonal fluctuations and reflect typical production conditions. Shorter periods may be considered if data on a full year are not yet available. Longer averaging periods may be considered but shall not exceed three years. Any averaging period deviating from the default shall be flagged and justified.

8.2.2 Temporal validity

Environmental impacts shall by default be reported for the most recent year (reporting or calendar year). An annual check is mandatory to ensure data actuality. To perform the annual check, the initial screening analysis should be updated based on data for the most recent year. An update of data is mandatory if the reported impacts increase by 10% or more based on the screening analysis compared to the previous reporting period. Additionally, an update of data is mandatory in the following situations (adapted from GHG protocol):

- Structural changes in operation to the product system under study, including significant process change in operation, technology advancement, raw material or energy changes.
- Changes in calculation methodology or improvements in the accuracy of emission factors or activity data or inclusion of new types of sources that result in a significant impact on the emissions data.
- Discovery of significant errors, or a number of cumulative errors that are collectively significant.

8.2.3 Geography

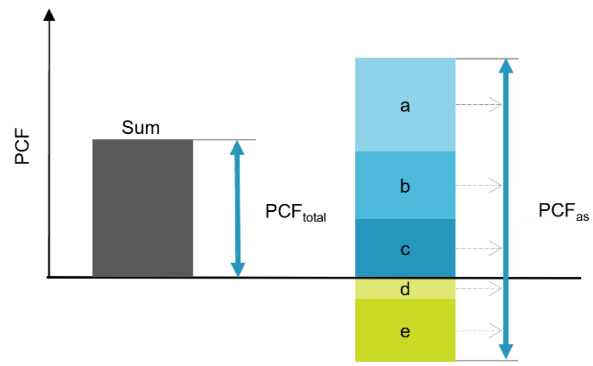
Environmental impacts shall by default be reported on the plant level. If no plant specific data is available or accessible, averaging over a region or country may be considered but shall be flagged as such.

8.2.4 Primary data share

The Primary Data Share (PDS) indicates the proportion of LCA data that is derived from primary data. To ensure transparency, the PDS indicator should be calculated and reported for each data point to show the extent of primary data usage. In the following, the PDS is explained using the PCF as an example; the calculation method applies analogously to all impact categories. Within the context of AX, the PDS for the impact category climate change shall be only reported for non-biogenic carbon, excluding biogenic carbon. Following the transition period, this reporting will shift to include biogenic carbon within the total PCF.

To maintain consistency in PDS values whether calculated for individual steps or across aggregated process chains the PDS must be based on the absolute sum of all positive and negative environmental impact / PCF contributions (e.g. PCF_{as}). These individual contributions (e.g. PCF_i) reflect either inputs from upstream suppliers or emissions from specific process steps carried out by the reporting organization. As illustrated in Figure 12, the concept and calculation of PCF_{as} is straight forward. In the absence of negative contributions, PCF_{total} and PCF_{as} are equivalent. In instances where PCF_{as} is not available, the PCF_{total} function should be used as a backup for PDS calculation.

$$PCF_{as} = \sum_i |PCF_i|$$



Contribution	PCF_i	$PCF_{total,i}$	$PCF_{as,i}$
a	1.75	1.75	1.75
b	1.25	1.25	1.25
c	1.00	1.00	1.00
d	-0.50	-0.50	0.50
e	-1.25	-1.25	1.25
Results		2.25	5.75

Figure 12. Definition of PCF_{as}

The introduction of PCF_{as} now allows for the definition of primary data shares:

$$PDS_{PCF} = \frac{|Part\ of\ PCF\ based\ on\ primary\ data\ [kg\ CO_2\ eq.]|}{PCF_{as}[kg\ CO_2\ eq.]}$$

When multiple individual PCF contributions are reported, each with their own primary data share (PDS_i), the aggregated PDS should be determined as a weighted average, where the weights are the absolute PCF contributions of each component.

$$PDS_{aggregated} = \frac{\sum_i (|PCF_{total,i}| \times PDS_i)}{\sum_i PCF_{as,i}}$$

An example can be found in the AX LCA Guidance Document.

8.2.5 Data quality rating

In AX, companies determine the LCA based on the following data sources (see Figure 13 for reference):

1. Internal primary data, which refers to data collected from processes operated directly by the reporting company,
2. Primary data from external parties within the supply chain, meaning data related to processes not performed by the company itself but provided by its suppliers,
3. Secondary data used when the process is outside the company's operations and no primary data is available from suppliers.

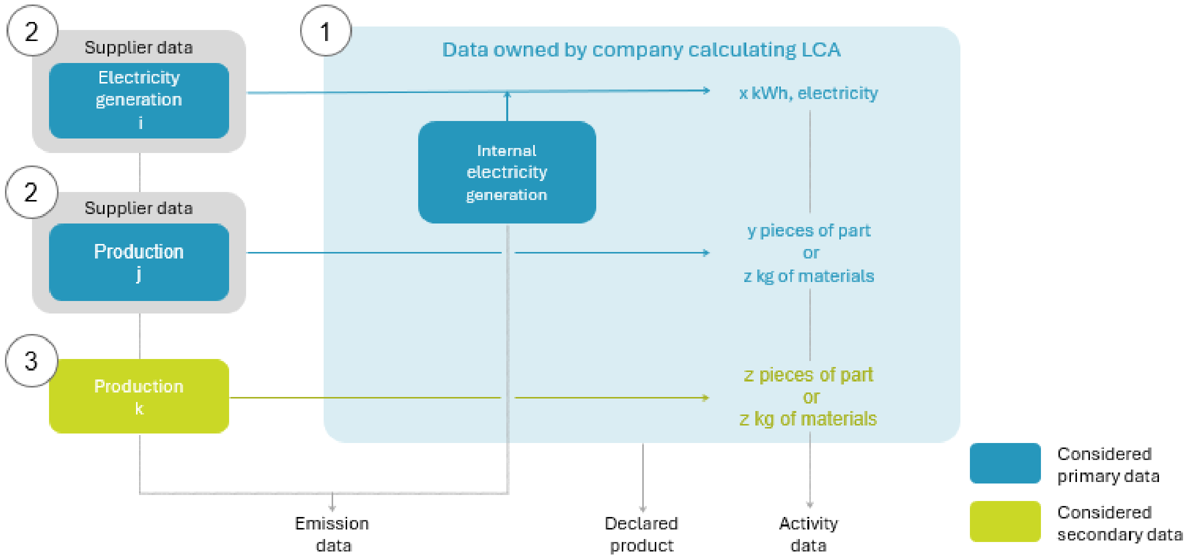


Figure 13. Data sources for PCF calculation

As part of the data collection phase, companies are required to evaluate the quality of their activity data, emission factors, and/or direct emissions data using Data Quality Ratings (DQR). The data quality assessment will be required after the transition period.

Currently, companies are able to calculate LCAs within a cradle-to-gate system boundary using various types of data. The quality of this data can vary considerably. Conducting data quality assessments provides a clear picture of the reliability and credibility of both the input data and the resulting LCA figures.

Four data quality indicators are to be applied when evaluating data quality. These indicators are as follows:

- Technological representativeness (TeR): the degree to which the data reflects the actual technology(ies) used in the process.

- Temporal representativeness (TiR): the degree to which the data reflect the actual time (e.g., year) or age of the process.
- Geographical representativeness (GeR): the degree to which the data reflects actual geographic location of the processes within the inventory boundary (e.g., country or site).
- Completeness: the degree to which the data are statistically representative of the relevant activity. Includes the percentage of locations for which data is available and used out of the total number that relate to a specific activity. Also addresses seasonal and other normal fluctuations in data.

Evaluating data quality during the data collection phase enables companies to implement improvements more effectively than if such assessments were conducted after data gathering is complete. Both primary and secondary data must be assessed to determine their accuracy in reflecting the actual production of the product being analyzed.

The data quality rating provided by the original database does not always apply directly to secondary data. Instead, it should be used as a reference point for evaluating how representative the data is of the specific product under investigation. This means assessing how well it mirrors real production conditions within the supply chain.

Each LCA must include a calculated and reported data quality rating based on the four criteria listed above. These criteria are assessed using a semi-quantitative scoring system, as outlined in Table 5. The data quality is categorized into five levels, ranging from 1 (best) to 5 (worst). The indicators for representativeness (technological, geographical, temporal) and completeness describe how accurately the selected data and processes reflect the system being analyzed.

Table 5: Data quality rating criteria

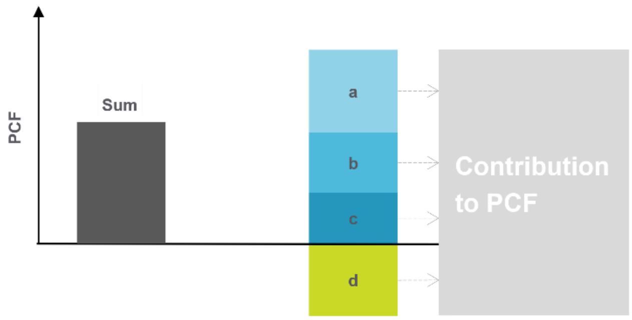
	1	2	3	4	5
TeR	Primary data and site-specific. It directly reflects the exact technology, processes, and operating conditions.	Primary data reflecting the company-specific and same technology or process. Not necessarily plant specific, can be an average.	Based on industry average data for a equivalent technology, or data from a generally comparable but not identical technology (secondary data).	Based on data reflecting a technological proxy, similar but not same technology, irrespectively if based on averaged or supplier specific data.	Data is generic, from a different or unknown technology.
TiR	The difference between "Reference Period End" of the dataset and "Date of Issue" is ≤ 1 year.	The difference between "Reference Period End" of the dataset and "Date of Issue" is >1 and ≤ 2 years.	The difference between "Reference Period End" of the dataset and "Date of Issue" is >2 and ≤ 3 years.	The difference between "Reference Period End" of the dataset and "Date of Issue" is >3 and ≤ 4 years.	The difference between "Reference Period End" of the dataset and "Date of Issue" is >4 years.
GeR	Based on data reflecting the country subdivision in which the product has been manufactured	Based on data pertaining the country, in which the product has been manufactured. The area where the dataset is generated is valid for the geographical area where the site is located.	Based on data pertaining the geographical region (e.g. Europe, Asia, N. America), in which the product has been manufactured. The area where the dataset is generated is valid for the geographical area where the site is located.	The dataset has been created based on global averages.	Based on data with a geographical scope which is either unknown or pertaining a country, or region not including the site in which the product has been manufactured.
Com-plete-ness	The data covers (nearly) all relevant locations or activities, including significant seasonal and operational fluctuations, ensuring full statistical representativeness	The data covers > 85 % of relevant locations / activities and include most seasonal and operational fluctuations, providing high representativeness with only minor gaps.	The data covers between 70 % and 85 % of the relevant scope, with only partial inclusion of seasonal and operational variations, leading to limited statistical representativeness.	The data cover between 50 % and 70 % of the relevant scope, with only partial inclusion of seasonal and operational variations, leading to limited statistical representativeness.	The data cover less than 50 % of relevant locations or activities, lack major seasonal or operational aspects or the statistically representative is unknown.

To ensure clarity and transparency, companies are required to report the individual ratings for each data quality indicator separately. If the product under study is manufactured at multiple locations, the corresponding DQRs must be determined based on a production volume-weighted average across those sites.

The propagation of data quality through the supply chain should follow the same approach as used for the Primary Data Share (PDS). In instances where a DQR is not provided, the lowest possible data quality score shall be used as default, as defined in the sample scoring table (Table 5). Therefore, the lowest rating may signify either the presence of genuinely low data quality or the absence of any reported rating.

8.2.5.1 Aggregated data quality rating

When calculating the aggregated data quality, the relative contribution of each process is to be based on the absolute values of the LCA. This ensures accurate weighting even in cases where individual processes show negative LCA values, such as when there is for example for the impact category climate change CO_2 uptake from biogenic or fossil sources with a characterization factor of -1 kg CO_2 eq. per kg CO_2. The utilization of absolute values is essential in preventing underestimation of the influence of such processes and ensuring the integrity of the aggregated DQR and PDS calculation. For reference, please see Figure 14.



Contribution	PCF	DQR	PDS
a	3.00	1.90	0.80
b	1.50	1.30	0.90
c	1.75	2.30	0.60
d	-2.00	2.80	0.40
Results	w/o correction	1.40	0.90
	w/ correction	2,10	0.60

Figure 14. Calculation of an aggregated DQR and PDS

For the calculation of the aggregated DQR the following procedure applies:

1. Identify the most relevant processes that together account for at least 80% of the total LCA of the dataset. Rank these processes from highest to lowest based on their contribution to the overall LCA
2. For each of these most relevant processes, please assess the four DQR criteria TeR, TiR, GeR, Comp. and R. The values for each criterion are to be determined in accordance with the specifications outlined in Table 5.
3. Calculate the relative contribution of each selected process to the 80% subset of the LCA.
4. The weighted average for each DQR criterion (TeR, TiR, GeR, and Comp) should be calculated using the process contributions from Step 3 as weights. The general formula for the weighted average is shown below using the TeR as an example:

$$\overline{Te_R} = \sum_{i=1}^{n} Te_{R_i} \times w_i$$

With:

- Te_{R_i} is the TeR score of process i
- w_i is the relative contribution (weight) of process i to the 80% LCA subset
- n is the number of relevant processes contribution in the LCA subset

5. Calculate the total DQR of the dataset using the next equation, where the weighted averages TeR, TiR, GeR and Comp are obtained from the previous steps

$$DQR = \frac{\overline{Te_R} + \overline{G_R} + \overline{Ti_R} + \overline{Comp}}{4}$$

8.2.6 Reporting carbon offsets

In order to share LCA data across the AX network, it is necessary to share the full cradle-to-gate LCA results. Any carbon offsets (as defined in the glossary) must be excluded from the reported results.

If applicable, suppliers providing LCA data to customers shall report any carbon offsets separately from the core LCA data. This applies to both certified and non-certified offsets. In instances where carbon offsets have been purchased, the origin and details of these offsets must be disclosed transparently, including references to the original certificates.

For guidance on incorporating renewable electricity certificates, please refer to Section 5.2.4. Carbon-neutrality claims for parts and components based on carbon offsetting are outside the scope of this LCA Rulebook.

Annex A – Catena X as the basis of this rulebook

This rulebook builds upon foundational elements of the CX-PCF Rulebook Version 4.0. Where applicable, content has been either directly transferred or adapted to reflect the specific regulatory, operational, and data realities of the aerospace sector.

The following table identifies all such transfers and clarifies the extent of reuse. This is intended to ensure transparency, traceability, and alignment with intellectual property and compliance requirements**.**

Table 6. Methodological Comparison with the CX-PCF Rulebook

Chapter in AX	Chapter in CX	Methodological Comparison
1.1 – Purpose and Scope of the Rulebook	Chapter 1.1 to 1.4	AX and CX both aim for standardization and data consistency. AX adds full LCA guidance and stricter data quality rules for the aerospace sector, with strong focus on interoperability with CX and global standards.
1.2 – Life Cycle Assessment in the Aerospace Industry	Chapter 1.1 to 1.4	Both use ISO standards and WBCSD alignment. CX focuses on automotive PCF; AX addresses greater aerospace emissions and data gaps, extending CX principles to full LCA and broader impact categories and aligning with IAEG WG12.
2.1 – Version	Chapter 2.1	Same approach with minor adjustments to adapt to the aerospace sector. AX and CX require LCAs/PCFs to follow the latest version of their rulebooks.
2.2 – Terminology	Chapter 2.2	Identical use of ISO terms (“shall”, “should”, “may”, “can”) for defining requirements and recommendations.
2.3 – Topics out of Scope	Chapter 2.3	Both exclude full recycling strategies beyond secondary materials and focus on carbon footprints. AX applies this to aircraft and components; CX applies it to automotive parts.

Chapter in AX	Chapter in CX	Methodological Comparison
2.4 – Catena-X as the Basis for the Rulebook	—	The AX LCA Rulebook references the CX PCF Rulebook v4 as its structural and methodological foundation.
2.5 – Transition Period	Chapter 2.4	Both define a transition period with optional rules becoming mandatory later. CX v4 extends the transition period to end of 2027 to support SME adoption. AX uses the same phased approach to facilitate adoption of new and complex rules.
3.1 – Relationship	Chapter 3.1	Both rulebooks build on ISO 14040 and 14044. CX builds additionally on ISO 14067 and is closely aligned with the WBCSD Pathfinder Framework, with further alignment with sector initiatives such as TFS, worldsteel, IAI and European Aluminum as accepted drop-in standards (see CX Annexes A 3–A 6). AX adds alignment with IAEG and the CX-PCF rulebook itself.
3.2 – Hierarchy of Conformity	Chapter 3.2	Both use a clear hierarchy: ISO standards first, followed by industry-specific and sector-specific rules. AX mirrors CX but applies it to LCA rather than just PCF, emphasizing downstream transparency for aerospace data. Both require that information on the applied methods or standards shall be shared downstream as part of the data model.
4.1 – Introduction to LCA and PCF Methodology	Chapter 4.1	Both AX and CX apply attributional LCA/PCF based on ISO 14040, 14044, and 14067, using IPCC AR6 characterization factors and GHG Protocol gases. CX v4 now mandates the total GWP including biogenic CO_2 uptake (T1) as the lead indicator for PCF, PDS, DQR and verification share, whereas previously this was optional during the transition period. AX adopts CX PCF calculation structure, including the −1/+1 approach for biogenic carbon and separate reporting of emission positions A–H, but extends the methodology to a full aerospace LCA framework with plans to add more

Chapter in AX	Chapter in CX	Methodological Comparison
		environmental impact categories beyond climate change in alignment with IAEG WG12.
4.2 – Functional and Declared Unit	Chapter 4.3	CX emphasizes declared units (e.g., 1 piece, 1 kg) for PCF comparability; AX balances both functional and declared units, aligning with full LCA needs and enabling aerospace-specific data exchange. AX also introduces a functional conversion factor concept considering lifetime and mechanical/thermal properties.
4.3 – System boundaries and completeness requirements	Chapter 4.2 & 4.3	Both AX and CX use a cradle-to-gate system boundary, excluding use and end-of-life. AX applies similar boundary logic and exclusion criteria, including a 3% cut-off threshold, and requires a documented screening process for identifying insignificant processes. The structure and exclusions, like employee commuting or capital goods, are aligned, with AX applying them specifically to aircraft production contexts. Crucially, AX aligns with the updated CX v4 requirement that data recalculation is mandatory if the reported impacts increase by 10% or more based on the screening analysis compared to the previous reporting period.
4.4 – LCI modelling framework and handling of multifunctional processes	Partially addressed in Chapters 4.2, 5.1.2, and 6	CX limits PCF to climate change (GWP). AX plans to expand to additional LCA categories identified by IAEG as critical for aerospace: climate change, resource use, photochemical ozone formation, acidification, and particulate matter, reflecting the industry's broader environmental priorities.
4.5 – Conducting the Life Cycle Impact Assessment (LCIA)	—	AX adds a dedicated chapter for the LCIA process for conducting full LCAs. CX does not detail LCIA as a separate phase. AX recommends the Environmental Footprint (EF) LCIA method (currently EF 3.1) for standardized characterization, in alignment with the IAEG LCA Aerospace Framework.

Chapter in AX	Chapter in CX	Methodological Comparison
5.1 – Accounting for LCA/ PCF	Chapter 5.1	Both adopt attributional LCA and follow ISO 14067 for PCF calculation; CX provides a standardized allocation hierarchy with sector drop-in rules, while AX applies the same logic but integrates aerospace-specific modelling practices and emphasizes transparency in stakeholder assumptions.
5.2 – Additional guidance	Chapter 5.2	CX provides modular guidance for specific topics like transport, waste, recycling, electricity, and chain-of-custody using predefined categories and decision rules, critically introducing structured requirements for Prospective PCF. AX mirrors this structure (not including prospective PCF) but adapts it to aerospace context, extends applicability beyond PCF. AX also generally excludes emissions from the construction or dismantling of all energy infrastructure (capital goods), which is contrary to the CX mandate to include infrastructure emissions for electricity generation to properly account for non-dispatchable renewable sources. AX introduces an additional fifth chain-of-custody model ("controlled blending"). As the book and claim model is not aligned with ISO 14040/44, AX only recommends it as an informative tool, but not as solely useable chain of custody model.
6 – Impact Categories	–	Chapter 6 is new to AX and has no direct counterpart in CX. CX-PCF v4 addresses only climate change (GWP). AX consolidates rules for six impact categories in a dedicated chapter: Climate Change (PCF), Resource Use (Fossils), Resource Use (Minerals and Metals), Photochemical Ozone Formation, Acidification, and Particulate Matter. This chapter is based on the IAEG LCA Aerospace Framework and the EF LCIA method (EF 3.1). During the transition period, only Climate Change (PCF) is mandatory; the other categories become mandatory afterwards. For Climate Change, AX repeats the key PCF rules (dual totals T1/T2, positions A–H, IPCC AR6 characterization factors) in a self-contained section to support direct data exchange.

Chapter in AX	Chapter in CX	Methodological Comparison
7.1 – Primary data	Chapter 6.1	CX defines primary data strictly as directly measured or calculated values, excluding averages; AX adopts the same definition but adds emphasis on traceability, documentation, and confidentiality to address the complexity of aerospace supply chains.
7.2 – Secondary data	Chapter 6.2	CX permits secondary data when primary data is unavailable, prioritizing updated IPCC-aligned datasets; AX adopts this structure but requires more detailed documentation of data provenance, representativeness, and limitations to ensure transparency in aerospace supply chains. AX also gives a recommendation for secondary databases, based on IAEG LCA Aerospace Framework.
8.1 – Data model	Chapter 7.1	CX defines a standardized PCF data model for exchange, focused on minimum required elements for comparability across the automotive network. AX aligns structurally but expands the model to support full LCA data exchange and accommodates aerospace-specific elements such as confidentiality tagging and multi-tier traceability.
8.2 – Details on the required data elements	Chapter 7.2	Both specify key data fields such as time period, geography, and data quality to ensure consistency in PCF/LCA data exchange; AX retains the CX structure but adjusts interpretation of fields like temporal validity and data quality to reflect longer aerospace lifecycles and more fragmented supply chains. Crucially, AX mandates that the GWP total including biogenic CO_2 uptake (T1) shall be used as the mandatory basis for calculating both the PDS and the DQR. Furthermore, AX aligns with the updated CX requirement that data recalculation is mandatory if the reported impacts increase by 10% or more based on the screening analysis.

Annex B – Additional guidance on classifying waste vs co-product

'Deliberately produced' means that the manufacturing process directly seeks to produce the material/component, i.e. is the result of a technical choice. 'Further use is certain' means that it is not a mere possibility but a certainty; in other words, it is guaranteed that the material will be used. This criterion may be indicated through, for example:

- Existence of contracts between the material producer and subsequent user.
- A financial gain for the material producer.
- A solid market (sound supply and demand) existing for this further use.
- Evidence that the material fulfils the same specifications as other products on the market.

'Used directly without any further processing other than normal industrial practice' means that if a production residue has to be treated before it can be used, this may indicate a waste treatment operation. Those treatment techniques that address typical waste-related characteristics of the production residue, such as its contamination with components which are hazardous or not useful, would prevent classification as non-waste. On the other hand, a treatment which is normal industrial practice, e.g. modification of size or shape by mechanical treatment, does not prevent the production residue from being regarded as a by-product.

'Normal industrial practice' can include all steps which a producer would take for a product, such as the material being filtered, washed, or dried; or adding materials necessary for further use; or carrying out quality control. However, treatments usually considered as a recovery operation cannot, in principle, be considered as normal industrial practice in this sense. Recovery operations are divided into three sub-categories: preparing for re-use, recycling, and other recovery.

'Produced as an integral part of a production process' means that the process where the co-product is generated has to be an integral part of a production process. Therefore, a material, which is made ready for further use through an integral part of a production process, can be regarded as a co-product. If a material leaves the site or factory where it is produced in order to undergo further processing, this may be evidence that such tasks are no longer part of the same production process, thus disqualifying it as a co-product.

'Further use is lawful' means that the further use of the material must be lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements at the national level for the specific use and will not lead to overall adverse environmental or human health impacts.

Reference for Annex B: "Guidance on the interpretation of key provisions of Directive 2008/98/EC on waste"[18]

[18] European Commission (2012): Guidance on the interpretation of key provisions of Directive 2008/98/EC on waste. Link: Guidance_on_waste_of_Directive_2008/98/EC.pdf

Annex C – Imprint

Contributing partners

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