Factory-X PCF GUIDANCE

Product Carbon Footprint Calculation for discrete Manufacturing

Factory-X

The Digital Ecosystem

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IMPRINT

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Glossary

Allocation: The process of assigning material and energy consumption, and thus emissions, to individual products, especially in manufacturing facilities that produce more than one product. This is crucial when processes and their emissions cannot be directly attributed to a single product. The document outlines economic and physical allocation methods.

Allocation Keys: Specific parameters or ratios used to distribute emissions among different products or processes during allocation. Examples include energy consumption-based, quantity-based, area-based, time-based, and economic allocation keys. These are defined to improve comparability between PCFs of similar products from different manufacturers.

Apportioned Emissions: Emissions arising from shared facility services (similar to overhead costs) that cannot be directly attributed to a single discrete manufacturing step for a specific product. These emissions, such as those from heating, cooling, air conditioning, ventilation, water supply, and lighting of production halls, must be distributed or "apportioned" among the products manufactured within that environment using appropriate allocation keys.

Catena-X PCF Rulebook V4.0: A foundational document that provides the framework and rules for calculating Product Carbon Footprints (PCF), particularly within the context of the Catena-X initiative. The "Factory-X PCF Guidance" document supports companies in applying this rulebook consistently.

CNC: Computer Numerical Control (CNC) is an automated manufacturing method in which pre-programmed computer software precisely controls the movement of machine tools (such as mills, lathes, drills, and laser cutters) to shape raw materials into finished parts.

Cut-off Rules: Guidelines that allow for the exclusion of certain processes, inputs, and outputs from the PCF calculation if their combined contribution is deemed insignificant to the overall carbon footprint. According to the Catena-X PCF Rulebook V4.0, these exclusions are permissible if they account for less than 3% of the total PCF, ensuring a minimum coverage of 97%.

Declared Unit: A specified unit by which the product carbon footprint is assessed. The Catena-X PCF Rulebook outlines recommended declared units, such as "1 piece" for countable products or "1 kg" for materials, often with specific conditions regarding packaging and product identification.

Direct Emissions: Emissions that arise from activities directly controlled by the reporting company, such as those from its own boilers, production lines, or vehicles. These are a component of the overall PCF calculation.

Discrete Manufacturing: A production environment characterized by the creation of distinct, individual products. The "Factory-X PCF Guidance" document is specifically tailored to help companies in this sector apply the Catena-X PCF Rulebook.

Economic Allocation: An allocation method used when there is a significant difference in value between co-products. The Catena-X PCF Rulebook specifies a 1:5 threshold for applying this method, where emissions are apportioned by the revenue, market value, or margin of individual products.

Energy Emissions: Emissions resulting from energy use, calculated by multiplying energy consumption by the emission factor of the energy source. This is a critical component of PCF calculation, especially for electricity.

GHG: A greenhouse gas (GHG) is any gas in the Earth's atmosphere that traps heat and contributes to the greenhouse effect, leading to global warming and climate change. Key GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. In a business context, GHGs are measured and managed to understand and reduce an organization's climate impact.

IoT: Internet of Things (IoT) is a network of physical objects (from household appliances to industrial machinery) embedded with sensors, software, and connectivity that allows them to collect and exchange data over the internet or other networks, largely without human intervention.

LMB: Laser Beam Melting (LBM) is an additive manufacturing (metal 3D printing) process in which a high-power laser fully melts and fuses metal powder layer by layer to build a solid, near-net-shape part directly from a digital 3D model. The process typically takes place in an inert gas atmosphere to prevent oxidation and allows production of complex, high-density metal components with properties comparable to conventionally manufactured parts.

Multi-Output Allocation Decision Procedure: A procedure outlined in the Catena-X PCF Rulebook (Chapter 5) to address situations in manufacturing facilities where multiple products inevitably pass through a single meter for energy and/or material consumption. This procedure guides the choice between process subdivision, system expansion, or allocation.

PCF Cradle-to-Gate: A specific scope of Product Carbon Footprint calculation that includes all emissions from raw material extraction ("cradle") up to the point where the product leaves the factory gate, before it reaches the customer. It is the sum of the Own Production PCF and the Upstream PCF.

Physical Allocation: The standard allocation method for assigning material and energy consumption to individual products in multi-product manufacturing facilities, particularly for building emissions or idle-state emissions. This method is applied in cases where economic allocation is not suitable, and it uses physical output quantities (e.g., number of pieces, volume, mass) or other physical parameters.

Product Carbon Footprint (PCF): A measure of the total greenhouse gas emissions generated by a product throughout its lifecycle, or a defined portion thereof (e.g., cradle-to-gate). The calculation of PCF is a central theme of both the Catena-X PCF Rulebook and the guidance document.

Process Subdivision: The act of breaking down measurement infrastructure to a level where the manufacturing process of an individual product can be measured separately in terms of space and time. This is a key approach to improve data quality for PCF calculations in multi-output processes.

Scrap Management: The process of including production scrap and waste in the emissions calculation. This involves accounting for recyclable scrap (e.g., steel chips) and the emissions from transporting it to a recycler, as well as consumable-related scrap treated as waste until final disposal, as detailed in the Catena-X PCF Rulebook.

Sub-metering: The practice of installing additional meters to measure energy consumption at a more granular level (e.g., per machine or production area) rather than relying on a single main meter. This is highlighted as the most effective way to improve data quality and primary data share in discrete manufacturing for PCF calculations.

System Boundaries: The defined scope of a life cycle assessment, outlining which processes and material/energy flows are included in the PCF calculation. In the context of the Catena-X PCF Rulebook, these boundaries typically cover life cycle stages up to product delivery, with a focus on production and outbound delivery.

System Expansion: An approach applicable when a single production process intentionally yields two outputs with different functions, and a clear, dominant alternative production route exists for one of the outputs based on sector consensus. This is considered rare in discrete manufacturing.

Upstream PCF: The portion of the Product Carbon Footprint that accounts for emissions generated in the supply chain before the product reaches the reporting company's factory gate. This includes emissions from raw materials and their transport.

Utilities/Auxiliaries: Inputs to the production process that are not directly part of the product but are necessary for its manufacturing, such as heating, lighting, maintenance services, or lubricants. Their PCF can be estimated conservatively for screening purposes.

General information about the Guidance Document

The PCF Guidance Document supports companies in applying the Catena-X PCF Rulebook V4.0[1] / Manufacturing-X PCF Guideline[2] correctly and consistently across real-world discrete manufacturing environments. It does not replace the Catena-X PCF Rulebook or any applicable norm or standard - rather, it serves as a practical companion for practitioners working to scale Product Carbon Footprint (PCF) calculation within their organizations and supply chains.

The primary objective of this document is to increase the specificity of reported emissions relative to actual production processes, and to improve the comparability of PCF results across companies and value chains. To achieve this, the guidance provides:

- Practical workflows and examples to reduce interpretation effort when applying the Rulebook
- Clarification of complex and frequently discussed calculation topics to ensure consistent understanding and application

The document offers targeted guidance across the following PCF calculation topics: Calculation, Allocation, Electricity, Logistics, and Waste & Recycling.

All guidance in this document is grounded in the Catena-X PCF Rulebook V4.0 / Manufacturing-X PCF Guideline. In cases of conflict or ambiguity, the Rulebook takes precedence.

In this document we will reference the Catena-X PCF Rulebook V4.0. As the content and chapter structure of the Manufacturing-X Guideline is based on The Catena-X PCF Rulebook V4.0, the references equivalently point to the corresponding sector agnostic Manufacturing-X Guideline chapters.

[1] Catena-X Automotive Network e.V., "Catena-X Product Carbon Footprint (PCF) Rulebook," Version 4.0, September 2025. [Online]. Available: https://catenax-ev.github.io/docs/non-functional/overview/

[2] Manufacturing-X Guidance Board, "Manufacturing-X Product Carbon Footprint (PCF) Guideline," Version 1.0, 2025. [Online]. Available: https://mx-guidanceboard.org/wp-content/uploads/MX-PCF-Guideline_V1_0.pdf

1 Scope and System Boundary

Note:
The content of the following chapters was taken from the Catena-X PCF Rulebook V4.0.

1.1 System Boundary

The scope of a life cycle assessment should be tailored to its purpose. In the context of the Manufacturing-X initiative, the PCF aims to objectify purchasing decisions regarding CO2e emissions. The focus is on the life cycle stages up to product delivery, whereby production and delivery (outbound) are reported individually. Product-agnostic sector specifications can be written for these life cycle stages that enable a high degree of comparability, which is not possible for subsequent life cycle stages (use stages are by definition product-category-specific).

Generally, the Catena-X PCF Rulebook rules apply. Therefore, the system boundaries are those of the most recent version of the Catena-X PCF Rulebook. Factory-X specifically aims to determine manufacturing-related emissions in its own manufacturing environment in a more representative and specific manner. However, the PCF's system boundary covers the entire production system and therefore also emissions from the upstream supply chain, packaging or disposal of waste. All product-specific upstream emissions not included in the BOP (Bill of Processes), which this guidance addresses in more detail, must be covered by the BOM (Bill of Materials). BOM and BOP in practice form the bases for the inventory and must cover the entire system boundary.

Geography: In product accounting, there are no geographic system boundaries to consider. When using corporate accounting data for product accounting, it is important to ensure completeness. System boundaries of product and corporate accounting differ vastly.

Technology: All specifications and documentation of the PCF should be based on the company's manufacturing processes and not be generic.

Temporal: The reference period refers to the collection of the company's activity data. When defining time periods over which emissions are averaged, ensure the approach is appropriate. The PCF must be understood as a control variable. From a control engineering perspective, control variables must be recorded in such a way that a decision about an action can be made based on them. Following this logic, it is illogical for the sales department to record different PCFs for products every 15 minutes if customers make purchasing decisions regarding products only once a year. In this case, product emissions must be averaged over the year so that purchasing decisions are not subject to high noise and thus chance.
High frequency decisions for internal optimization only (not for external customer communication) are a special case and therefore an exception may apply: Some goods are traded at a very high frequency (e.g., electricity). If high-frequency purchasing decisions with potential environmental objectives are made here, it may make sense to average product emissions over very short time periods. However, each purchasing decision must lead to reduced CO2e emissions in the long term (the additionality criterion).
To manage product emissions in automated manufacturing on an intra-year basis, it is advisable to average consumption and emissions over shorter time periods (e.g., weekly), provided that it leads to a more efficient allocation of manufacturing resources or production planning, or simplified troubleshooting. However, these should be averaged into annual values for the customer, unless the customer can influence a specific batch during the purchasing decision (e.g., in the glass industry, where there are variable proportions of primary and secondary materials).

Specific to the use of activity data initially intended for Corporate Carbon Footprint (CCF)[3]:
"In general, GHG emissions not connected directly to the production system relevant for the product shall be excluded from the system boundaries. These are amongst others:

- Employee commuting and work travel
- Research and development, administration, or sales processes
- Auxiliary inputs not directly related to the production process (such as heating and lighting of associated office rooms, secondary services like maintenance, sanitary facilities, canteen services, facility management e.g., plant security and fire safety and general IT)
- Auxiliary inputs to maintain the manufacturing equipment
- Emissions from construction or dismantling of capital good (such as buildings, manufacturing equipment or any other infrastructure for transport, and media distribution, within or outside the control of the reporting company)"

1.2 Cut-off Rules

In principle, all processes and material and energy flows attributable to the system under analysis must be included in the PCF calculation. Where a screening analysis demonstrates that individual flows are insignificant to the overall carbon footprint, exclusions may be made for practical reasons, in accordance with ISO 14067 and the Product Environmental Footprint (PEF) method.
Process modules, inputs, and outputs may only be excluded if their combined contribution accounts for less than 3% of the total PCF. A minimum coverage of 97% must be achieved and documented through the screening analysis.

1.3 Declared Unit

The Catena-X PCF Rulebook outlines how the product carbon footprint is assessed for a declared unit. A functional equivalent is established by the data recipient, which falls outside the scope of the Catena-X PCF Rulebook. Possible declared units are piece, kilogram, liter, cubic meter, kilowatt hour, megajoule, ton kilometer, square meter, hour and megabit second.

Catena-X recommends the following declared units:

- For **countable products** (components or parts): **1 piece**, as specified in the part description, including a defined weight and part ID.
- For **materials** (bulk products or raw materials): **1 kg of the product**, regardless of its physical state (solid, liquid or gaseous), as its specific density is considered.
- If the specification includes **packaging**: **1 kg or 1 piece of the unpackaged product** at the factory gate. However, the PCF includes the PCF contribution of the packaging.

[3] Catena-X Automotive Network e.V., "Catena-X Product Carbon Footprint (PCF) Rulebook," Version 4.0, September 2025. [Online]. Available: https://catenax-ev.github.io/docs/non-functional/overview/

2 Product Carbon Footprint (PCF) Calculation

2.1 Challenges and Steps

Note:
The content was taken from the Catena-X Guidance Product Carbon Footprint (PCF) Calculation V1.1[4].

Challenges of Calculating a PCF

Calculating the PCF is a complex task that requires precise attention to detail and an in-depth understanding of the product's lifecycle. This complexity arises from a multitude of factors, each presenting its own unique challenges. The following list delves into these challenges in greater detail:

1 Data Collection and Complexity:
Gathering accurate and comprehensive data from multiple sources, including production planning, controlling, and suppliers, is time-consuming and often incomplete.

2 Data Accuracy:
Ensuring the accuracy of primary data, such as material weights, energy consumption, and emissions, is critical but difficult, especially when dealing with secondary data sources.

3 Supplier Coordination:
Engaging with suppliers to obtain upstream emissions data requires significant coordination and collaboration, which can be challenging without a standardized approach.

4 Emission Factors Variability:
The variability in emission factors, particularly for energy sources like electricity, adds complexity to the calculation process.

5 Waste Management:
Accurately accounting for waste and scrap generated during production stages is often overlooked, yet can be relevant for a precise PCF.

Figure 1: Challenges of calculating a PCF

Step-by-Step PCF Calculation

Step 1: Screening Analysis
Start by listing all materials and process steps (e.g., using the VDA LCA data collection form) to build an overview of the production system.

Step 2: Data Collection
For each process step, collect the data as accurately as possible:

- **Material Weight:** Information can be obtained from production planning.
- **Consumption of Energy, Utilities, and Auxiliaries:** This information can be derived from machine hourly rate calculations, which are typically handled by the controlling department.
- **Direct Emissions:** Coming from your production's own processes. These should be measured or stoichiometrically calculated.

[4] Catena-X Automotive Network e.V., "Guidance: Product Carbon Footprint (PCF) Calculation", Version 1.1, September 2024. [Online]. Available: https://catena-x.net/use-case-cluster/product-carbon-footprint/

- **Waste and Scrap Amount:** Record the amount of waste and scrap generated during the production process.
- **Transport Emissions:** Account for emissions from plant logistics (internal and external), if applicable.

Note:

- **Direct Emissions:** from activities you directly control (e.g., own boilers, production lines, vehicles).
- **Utilities/Auxiliaries**: Estimate conservatively for screening purposes to assess their PCF (e.g., grease, lubricants).
- **Scrap Management**: Production scrap and waste must be included in the emissions calculation. This includes recyclable scrap, such as steel chips. Therefore, the emissions from transporting scrap to the recycler must also be included. Refer to the Catena-X PCF Rulebook (section 5.2.5) for details on handling these flows. Consumable-related scrap, such as grease and final packaging, must be treated as waste and accounted for until its final disposal (section 5.2.4).
- **Energy emissions**: Emissions from energy use are calculated using energy consumption and the emission factor of the energy source, particularly for electricity. Electricity suppliers should provide information on the origin of their electricity (e.g., wind, coal, or gas) and a cradle-to-gate emission factor that covers all upstream emissions, including coal mining, losses, and waste treatment (see Catena-X PCF Rulebook section 5.2.6). If the supplier's cradle-to-gate PCF is unavailable but only the source mix is available, it can be combined with secondary data for the cradle-to-gate electricity supply. If no specific contractual information is available, use the residual mix, as required by the Catena-X PCF Rulebook.

Step 3: Upstream Data Collection

Request data from suppliers for all processes not under your control, including materials, components, consumables, and transportation modes and distances.

Step 4: Secondary Data Usage

Only use secondary data where primary data cannot be obtained and keep its use to a minimum. After collecting all primary and secondary data within the defined system boundaries, proceed with the PCF calculation.

2.2 Examples of PCF Calculations

The following section provides use case examples of PCF calculations based on the Catena-X Guidance Product Carbon Footprint (PCF) Calculation V1.1.

2.2.1 Example 1: Milled Part

To illustrate the calculation of a PCF, we use the example of a Milled Part. **Figure 2** shows an illustration of relevant processes to produce the Milled Part. The declared unit of this PCF is 1 piece Milled Part with a net weight of 24,5 kg.

Process illustration for a Milled Part

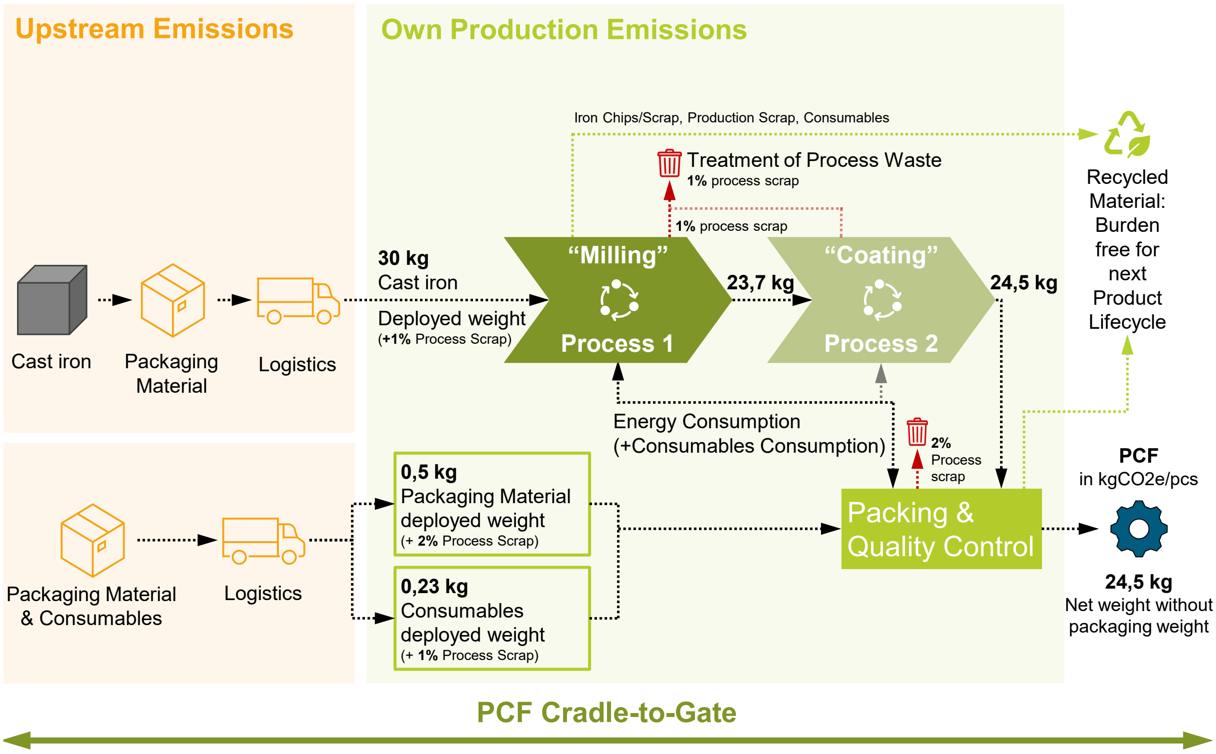

Figure 2: Processes to produce the Milled Part

NOTE:
Please note, that the GHG Emissions of the packaging are included but the declared unit refers to the mass of the unpackaged product.
This PCF calculation example refers to the Calculation of a total PCF excluding biogenic, as required for PCFs shared via Catena-X until end of 2027.

PCF Calculation Formulas

The **PCF Cradle-to-Gate** results from the sum of the **Own Production PCF** and the **Upstream PCF**.

PCF Cradle-to-Gate = **PCF Own Production** + **PCF Upstream**

NOTE:
The outbound transport of the Milled Part is under the control of the customer receiving it. Therefore, it is not included in the cradle-to-gate PCF

➔ The following formulas are an example of how to apply the rules.

PCF Own Production Formulas

PCF Own Production = "Milling" Electricity + "Milling" Grease + "Milling" Cooling Lubricant + Filter Paper + Carbide Tools + Metal Waste Transport + Consum-ables Waste Treatment + Quality Control & Packing Electricity + Packaging Material Waste Treatment

In this example, the formula for calculating the **PCF Own Production** consists of several values, each of which must be calculated using a separate formula. **In the following we lead through the calculation process.**

The formulas for calculating the values highlighted in gray can be found on later pages.

"Milling" Electricity

$$PCF\ milling = \underbrace{6{,}6\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 3{,}911\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- In the Process 1 "Milling" 1 % process scrap is generated.
- Includes electricity for the machine and electricity for pneumatic.

"Milling" Grease

$$PCF\ grease = \underbrace{0{,}01\ {}^{kg}/_{pcs}}_{\text{Weight of Grease}} * \underbrace{1{,}2\ {}^{kgCO2e}/_{kg}}_{\text{PCF Grease Material}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}012\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- Weight of grease per piece.
- PCF grease material is coming from secondary database.

"Milling" Cooling Lubricant

$$PCF\ cooling\ lubricant = \underbrace{0{,}05\ {}^{l}/_{pcs}}_{\text{Liter of Cooling lubricant}} * \underbrace{3{,}5\ {}^{kgCO2e}/_{l}}_{\text{PCF Cooling Lubricant}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}177\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- Liter of cooling lubricant per piece.
- PCF cooling lubricant is coming from secondary database.

Filter Paper

$$PCF\ filter\ paper = \underbrace{0{,}1\ {}^{kg}/_{pcs}}_{\text{Weight of Filter paper}} * \underbrace{1{,}38\ {}^{kgCO2e}/_{kg}}_{\text{PCF Filter Paper}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}139\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- Weight of filter paper per piece.
- PCF filter paper is coming from secondary database.

Carbide Tools

$$PCF\ carbide\ tools = \underbrace{0{,}06\,{}^{kg}/_{pcs}}_{\text{Weight of Carbide Tools}} * \underbrace{15\,{}^{kgCO2e}/_{kg}}_{\text{PCF Carbide Tools}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}909\,{}^{kgCO2e}/_{pcs}$$

NOTE:
- Weight of carbide tools per piece.
- PCF carbide tools is coming from secondary database.

Metal Waste Transport

$$PCF\ metal\ waste\ transport = \underbrace{108\ km}_{\text{Distance}} * \underbrace{6{,}3\ kg}_{\text{Weight of Metal Scrap}} * \underbrace{\left(0{,}147\,{}^{kgCO2e}/_{tkm}\right)}_{\text{PCF Well-to-Wheel lorry}} = 0{,}1\,{}^{kgCO2e}/_{pcs}$$

NOTE:
- Waste based on chips and carbide tools consumption.
- PCF Well-To-Wheel lorry data can be requested from the transport operator or taken from secondary database, refer to Catena-X PCF Rulebook section 5.2.3.1.
- Transport box weight is not included.

Consum-ables Waste Treatment

$$PCF\ consumables\ waste\ treatment =$$

$$(\underbrace{1{,}010E^{-}04\ kg}_{\text{Weight of Grease Waste}} + \underbrace{5{,}051E^{-}04\ kg}_{\text{Weight of Cooling Lubricant Waste}} + \underbrace{1{,}010E^{-}03\ kg}_{\text{Weight of Filter Paper Waste}}) * \left(\underbrace{0{,}016\,{}^{kgCO2e}/_{kg}}_{\text{PCF Logistic}} + \underbrace{1{,}087\,{}^{kgCO2e}/_{kg}}_{\text{PCF Incineration}}\right) = 0{,}002\,{}^{kgCO2e}/_{pcs}$$

NOTE:
- Consumables waste treatment of grease, cooling lubricant and filter paper.
- PCF Logistic calculation analogue to PCF Metal Waste Transport.
- PCF incineration data is coming from secondary database.
- PCF Well-To-Wheel lorry data can be requested from the transport operator or taken from Secondary database, refer to Catena-X PCF Rulebook section 5.2.3.1.

Quality Control & Packing Electricity

$$PCF\ packing = \underbrace{0{,}06\,{}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\,{}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} * \underbrace{\left(\frac{1}{(1-2\%)}\right)}_{\text{Scrap Factor}} = 0{,}036\,{}^{kgCO2e}/_{pcs}$$

NOTE:
- The packing process generates 2% process scrap in this example.
- The finished milled part is subjected to a quality check in this process step and packaged in plastic film.

Packaging Material Waste Treatment

$$PCF\ packaging\ waste = \underbrace{0{,}01\ kg}_{\text{Weight of Foil Waste}} * \left(\underbrace{0{,}016\,{}^{kgCO2e}/_{kg}}_{\text{PCF Logistic}} + \underbrace{1{,}087\,{}^{kgCO2e}/_{kg}}_{\text{PCF Incineration}}\right) = 0{,}011\,{}^{kgCO2e}/_{pcs}$$

NOTE:
- PCF Logistic calculation analogue to PCF Metal Waste Transport.
- PCF incineration data is coming from secondary database.
- PCF Well-To-Wheel lorry data can be requested from the transport operator or taken from secondary database, refer to Catena-X PCF Rulebook section 5.2.3.1.

Required Formulas for Own Production

In the following, we come to formulas for calculating values that are required for the formulas of the PCF calculation of your Own Production:

PCF Electricity	"Milling" Electricity per piece	Electricity Packing

PCF Electricity

$$PCF\ electricity = \underbrace{0{,}8}_{\text{80\% Residual mix}} * \underbrace{0{,}725\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Residual mix, incl. losses}} + \underbrace{0{,}1}_{\text{10\% PV}} * \underbrace{0{,}056\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from PV, incl. losses}} + \underbrace{0{,}1}_{\text{10\% Wind}} * \underbrace{0{,}01\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Wind offshore, incl. losses}} = 0{,}587\ {}^{kgCO2e}/_{kWh}$$

NOTE: Required Data: Mix of energy carriers and emission factors of the individual energy sources

"Milling" Electricity per piece

$$Electricity\ per\ piece = \underbrace{5{,}47\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity per piece}} + \underbrace{1{,}13\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity for Pneumatic per piece}} = 6{,}6\ {}^{kWh}/_{pcs}$$

NOTE: Required Data: Electricity per piece of the process 1 "Milling" machine.

Electricity Packing

$$Electricity\ packing = \underbrace{12\ kWh}_{\text{Electricity per hour}} * \underbrace{0{,}9}_{\text{Facility Capacity Utilization (90 \%)}} * \underbrace{\frac{20\ {}^{sec}/_{pcs}}{3600\ sec}}_{\text{Cycle time}} = 0{,}06\ {}^{kWh}/_{pcs}$$

NOTE: Required Data: Electricity/hour, capacity and cycle time of the packing machine.

PCF Own Production Process

$5{,}297\ {}^{kgCO2e}/_{pcs}$ = "Milling" Electricity + "Milling" Grease + "Milling" Cooling Lubricant + Filter Paper + Carbide Tools + Metal Waste Transport + Consumables Waste Treatment + Quality Control & Packing Electricity + Packaging Material Waste Treatment

PCF Upstream Formulas

For the calculation of the **Upstream PCF**, there are several **key points** to keep in mind:

- Request data from suppliers for upstream processes.
- Include emissions from the transport of materials to your factory gate if responsible.

PCF Upstream = Cast Iron + Packaging Material + Consumables & Tools

The formula for calculating the value highlighted in gray can be found below.

Cast Iron

$$Upstream\ PCF\ cast\ iron = \underbrace{30\ {}^{kg}/_{pcs}}_{\text{Deployed Weight}} * \left(\underbrace{1{,}9\ {}^{kgCO2e}/_{kg}}_{\text{PCF Cast Iron}} + \underbrace{0{,}024\ {}^{kgCO2e}/_{kg}}_{\text{PCF Logistic \& PCF Packing}}\right) * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 58{,}303\ {}^{kgCO2e}/_{pcs}$$

NOTE: The PCF for Cast Iron and PCF Logistic & Packing is coming from the supplier.

Packaging Material

$$Upstream\ PCF\ packaging\ material = \underbrace{0,5\,{}^{kg}/_{pcs}}_{\text{Deployed Weight}} * \left(\underbrace{0,6\,{}^{kgCO2e}/_{kg}}_{\text{PCF Packaging Material}} + \underbrace{0,024\,{}^{kgCO2e}/_{kg}}_{\text{PCF Logistic \& PCF Packing}}\right) * \underbrace{\left(\frac{1}{(1-2\%)}\right)}_{\text{Scrap Factor}} = 0,318\,{}^{kgCO2e}/_{pcs}$$

NOTE: The PCF for Packaging Material and Logistic & Packing is coming from the supplier.

Consum-ables & Tools

$$Upstream\ PCF\ consumables = \left(\underbrace{1,327\,{}^{kgCO2e}/_{pcs}}_{\text{PCF Consum-ables \& Tools}} + \underbrace{5,41E^{-}03\,{}^{kgCO2e}/_{pcs}}_{\text{PCF Logistic \& PCF Packing}}\right) * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 1,346\,{}^{kgCO2e}/_{pcs}$$

NOTE: The PCF for Consumables & Tools and Logistic & Packing is coming from the supplier.

Required Formulas for PCF Upstream

Formulas for calculating values for the PCF Upstream Calculation (if it’s not provided by the supplier):

Consum-ables & Tools

$$PCF\ consumables\ \&\ tools =$$

$$\underbrace{0,05\,{}^{l}/_{pcs}}_{\text{Deployed Amount}} * \underbrace{3,5\,{}^{kgCO2e}/_{l}}_{\text{PCF Oil Emulsion}} + \underbrace{0,01\,{}^{l}/_{pcs}}_{\text{Deployed Amount}} * \underbrace{2,7\,{}^{kgCO2e}/_{l}}_{\text{PCF Vapori-sation of the oil contained}} + \underbrace{0,01\,{}^{kg}/_{pcs}}_{\text{Deployed Weight}} * \underbrace{1,2\,{}^{kgCO2e}/_{kg}}_{\text{PCF Grease}} + \underbrace{0,1\,{}^{kg}/_{pcs}}_{\text{Deployed Weight}} * \underbrace{1,38\,{}^{kgCO2e}/_{kg}}_{\text{PCF Filter Paper}}$$

$$+ \underbrace{0,065\,{}^{kg}/_{pcs}}_{\text{Deployed weight}} * \underbrace{15\,{}^{kgCO2e}/_{kg}}_{\text{PCF Carbide tools}} = 1,327\,{}^{kgCO2e}/_{pcs}$$

NOTE: The PCF for the Consumables & Tools is coming from the supplier.

PCF Upstream

59,967 $^{kgCO2e}/_{pcs}$ **=** Cast Iron **+** Packaging Material **+** Consum-ables & Tools

PCF Cradle-to-Gate of the finished Milled Part

The PCF of the finished Milled Part is calculated from the sum of the previous Upstream PCF and Own Production PCF. In our example, we have only considered Process 1 "Milling" in detail. However, the production process of the Milled Part also includes other processes that must also be taken into account in the overall calculation of the PCF (see Figure 2). The outbound transport of the Milled Part to the customer is not included in the Cradle-to-Gate PCF.

PCF Cradle-to-Gate = PCF Upstream + PCF Own Production + PCF Process 2

$$65{,}264\ ^{kgCO2e}/_{pcs} = 59{,}967\ ^{kgCO2e}/_{pcs} + 5{,}297\ ^{kgCO2e}/_{pcs} + (65{,}264 + Z = 59{,}967 + 5{,}297 + X)$$

PCF Contribution of estimated Grease

The amount of grease was estimated, based on refilling cycles. According to the screening analysis the grease PCF share is 0,019%, so that you are allowed to cut it off from the final assessment (cut-off approach, see section 4.3 in the Catena-X PCF Rulebook).

Relevance of estimated Grease

$$PCF\ contribution\ of\ grease = \frac{\overbrace{0{,}012\ ^{kgCO2e}/_{pcs}}^{\text{PCF Grease}}}{\underbrace{65{,}264\ ^{kgCO2e}/_{pcs}}_{\text{PCF Cradle-to-Gate}}} = 0{,}019\%$$

If we calculate the proportions of all PCF shares, we get the following breakdown. According to the cut-off rules, we can exclude material or energy flows from the final assessment if they are found to be insignificant, i.e. if their combined contribution to the total PCF is less than 3%.

Final PCF Cradle-to-Gate with cut-off

PCF Upstream

59,967 $^{kgCO2e}/_{pcs}$ = Cast Iron (89,33%) + Packaging Material (0,49%) + Consumables (2,06%)

PCF Own Production Process 1

5,236 $^{kgCO2e}/_{pcs}$ = „Milling" Electricity" (5,99%) + ~~„Milling" Grease"~~ (0,019%) + "Milling" Cooling Lubricant (0,27%) + Filter Paper (0,21%) + Carbide Tools (1,39%) + Metal Waste Transport (0,15%) + ~~Consumables Waste Treatment~~ (0,003%) + ~~Quality Control & Packing Electricity~~ (0,055%) + ~~Packaging Material Waste Treatment~~ (0,017%)

PCF Cradle-to-Gate with cut-off

$$65{,}203\ ^{kgCO2e}/_{pcs} = 59{,}967\ ^{kgCO2e}/_{pcs} + 5{,}236\ ^{kgCO2e}/_{pcs}$$

NOTE:

In our example, the values of the crossed-out PCF shares are so low that they fall under the cut-off criteria and are considered insignificant as they have an almost negligible impact on the overall PCF. According to Catena-X PCF Rulebook, a maximum cut-off of 3% is allowed (see section 4.3). In general, the cut-off is used for material or energy flows that require a significant amount of effort for data collection but have only a minor impact on the product's overall PCF.

PCF coverage with cut-off

$$PCF\ coverage\ with\ cut\text{-}off = \frac{\overbrace{65{,}203\ {}^{kgCO2e}/_{pcs}}^{\text{PCF Cradle-to-Gate with cut-off}}}{\underbrace{65{,}264\ {}^{kgCO2e}/_{pcs}}_{\text{PCF Cradle-to-Gate}}} = 99{,}91\%$$

In principle, this calculation can be used as a basis for further PCF calculations.

2.2.2 Example 2: Forged Part

To illustrate the calculation of a PCF, we use the example of a Forged Part. **Figure 3** shows an illustration of relevant processes to produce the Forged Part. The declared unit of this PCF is 1 piece Forged Part with a net weight of 2,59 kg.

Process illustration for a Forged Part

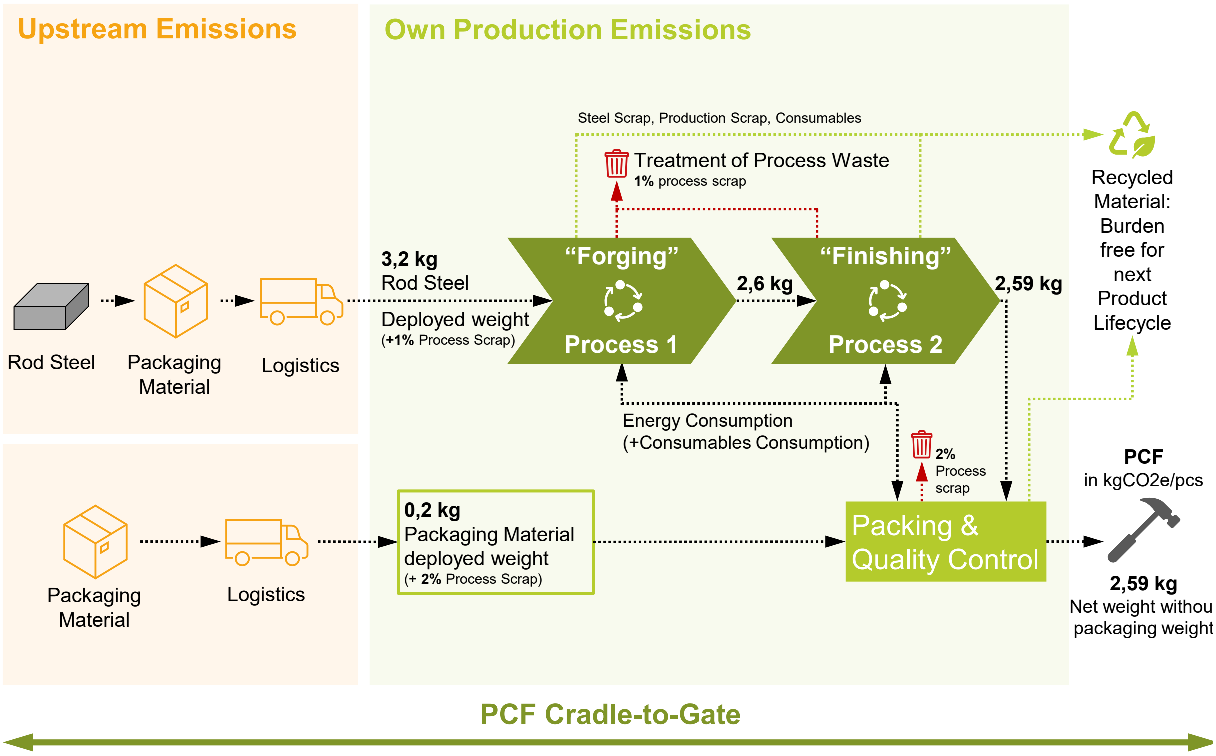

Figure 3: Processes to produce the Forged Part

NOTE:
Please note, that the GHG Emissions of the packaging are included but the declared unit refers to the mass of the unpackaged product.
This PCF calculation example refers to the Calculation of a total PCF excluding biogenic, as required for PCFs shared via Catena-X until end of 2027.

PCF Calculation Formulas

The **PCF Cradle-to-Gate** results from the sum of the **Own Production PCF** and the **Upstream PCF**.

PCF Cradle-to-Gate = **PCF Own Production** + **PCF Upstream**

NOTE:
The outbound transport of the Forged Part is under the control of the customer receiving it. Therefore, it is not included in the cradle-to-gate PCF.

NOTE:
This example was created using secondary data. The input data for the processes and emission factors are derived primarily from the FRED Carbon Footprint Calculator[5], which refers to industry averages.

➔ The following formulas are an example of how to apply the rules.

[5] FRED Carbon Footprint Calculator Version 2.5.0 – FRED GmbH

PCF Own Production Formulas

PCF Own Production	=	"Forging" (Process 1)	+	"Finishing" (Process 2)

In this example, the formula for calculating the **PCF Own Production** consists of several values, each of which must be calculated using a separate formula. **In the following we lead through the calculation process for Process 1 and Process 2.**

PCF Own Production "Forging" (Process 1)

PCF Own Production Process 1	=	"Cutting" Electricity	+	"Heating" Electricity Induction 1250°C	+	"Forming" Electricity Screw Press	+	"Tempering" Energy Gas Furnace	+	Steel Scrap Transport 1

The formulas for calculating the values highlighted in gray can be found on later pages.

"Cutting" Electricity

$$PCF\ cutting = \underbrace{0{,}054\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}032\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- The cutting process generates 1% process scrap in this example.

"Heating" Electricity Induction 1250°C

$$PCF\ steel\ heating = \underbrace{1{,}847\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 1{,}094\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- The heating process generates 1% process scrap in this example.

"Forming" Electricity Screw Press

$$PCF\ forming = \underbrace{0{,}049\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}029\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- The forming process generates 1% process scrap in this example.

"Tempering" Energy Gas Furnace

$$PCF\ tempering = \left(\underbrace{0{,}26\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} + \underbrace{2{,}912\ {}^{kWh}/_{pcs}}_{\text{Amount of Gas Energy}} * \underbrace{0{,}221\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Gas}}\right) * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}804\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- The tempering process generates 1% process scrap in this example.

Steel Scrap Transport 1

$$PCF\ steel\ scrap\ transport = \underbrace{360\ km}_{\text{Distance}} * \underbrace{0{,}6\ {}^{kg}/_{pcs}}_{\text{Weight of Steel Scrap}} * \underbrace{\left(5{,}071E^{-}05\ {}^{kgCO2e}/_{kgkm}\right)}_{\text{PCF Well-to-Wheel lorry}} = 0{,}011\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- Steel Scrap is produced by the cutting and forming process.
- PCF Well-To-Wheel lorry data can be requested from the transport operator or taken from secondary database, refer to Catena-X PCF Rulebook section 5.2.3.1.
- Transport box weight is not included.

Required Formulas for Own Production “Forging” (Process 1)

In the following, we come to formulas for calculating values that are required for the formulas of the PCF calculation of your Own Production Process 1:

PCF Electricity	Cutting“ Electricity per piece	“Heating“ Electricity per piece	“Forming“ Electricity per piece	“Tempering“ Electricity per piece	“Tempering“ Gas Energy per piece

PCF Electricity

$$PCF\ electricity = \underbrace{0{,}8}_{\text{80\% Residual mix}} * \underbrace{0{,}725\, {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Residual mix, incl. losses}} + \underbrace{0{,}1}_{\text{10\% PV}} * \underbrace{0{,}056\, {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from PV, incl. losses}} + \underbrace{0{,}1}_{\text{10\% Wind}} * \underbrace{0{,}01\, {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Wind offshore, incl. losses}} = 0{,}587\, {}^{kgCO2e}/_{kWh}$$

NOTE: Required Data: Mix of energy carriers and emission factors of the individual energy sources

“Cutting“ Electricity per piece

$$Electricity\ per\ piece = \underbrace{3{,}2\, {}^{kg}/_{pcs}}_{\text{Weight of the workpiece}} * \underbrace{0{,}017\, {}^{kWh}/_{kg}}_{\text{Electricity per kg}} = 0{,}054\, {}^{kWh}/_{pcs}$$

NOTE: The data for this process step comes from the FRED tool.

“Heating“ Electricity per piece

$$Electricity\ per\ piece = \underbrace{3{,}072\, {}^{kg}/_{pcs}}_{\text{Weight of the workpiece}} * \underbrace{0{,}601\, {}^{kWh}/_{kg}}_{\text{Electricity per kg}} = 1{,}847\, {}^{kWh}/_{pcs}$$

NOTE: The data for this process step comes from the FRED tool.

“Forming“ Electricity per piece

$$Electricity\ per\ piece = \underbrace{3{,}072\, {}^{kg}/_{pcs}}_{\text{Weight of the workpiece}} * \underbrace{0{,}016\, {}^{kWh}/_{kg}}_{\text{Electricity per kg}} = 0{,}049\, {}^{kWh}/_{pcs}$$

NOTE: The data for this process step comes from the FRED tool.

“Tempering“ Electricity per piece

$$Electricity\ per\ piece = \underbrace{2{,}6\, {}^{kg}/_{pcs}}_{\text{Weight of the workpiece}} * \underbrace{0{,}1\, {}^{kWh}/_{kg}}_{\text{Electricity per kg}} = 0{,}26\, {}^{kWh}/_{pcs}$$

NOTE: The data for this process step comes from the FRED tool.

“Tempering“ Gas Energy per piece

$$Gas\ energy\ per\ piece = \underbrace{2{,}6\, {}^{kg}/_{pcs}}_{\text{Weight of the workpiece}} * \underbrace{1{,}12\, {}^{kWh}/_{kg}}_{\text{Gas Energy per kg}} = 2{,}912\, {}^{kWh}/_{pcs}$$

NOTE: The data for this process step comes from the FRED tool.

PCF Own Production “Forging” (Process 1)

$1{,}971\ {}^{kgCO2e}/_{pcs}$ = “Cutting“ Electricity + “Heating“ Electricity Induction 1250°C + “Forming“ Electricity Screw Press + “Tempering” Energy Gas Furnace + Steel Scrap Transport 1

PCF Own Production “Finishing” (Process 2)

PCF Own Production Process 2 = “Blast Cleaning“ Electricity + Washing & Rust Protection Energy + Steel Scrap Transport 2 + Quality Control & Packing Electricity + Packaging Material Waste Treatment

The formulas for calculating the values highlighted in gray can be found on later pages.

“Blast Cleaning“ Electricity

$$PCF\ blast\ cleaning = \underbrace{0{,}039\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}023\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- The blast cleaning process generates 1% process scrap in this example.

Washing & Rust Protection Energy

$$PCF\ washing\ \&\ rust\ protection =$$
$$\left(\underbrace{0{,}052\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} + \underbrace{0{,}104\ {}^{kWh}/_{pcs}}_{\text{Amount of Gas Energy}} * \underbrace{0{,}221\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Gas}}\right) * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}054\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- The washing & rust protection process generates 1% process scrap in this example.

Steel Scrap Transport 2

$$PCF\ steel\ scrap\ transport = \underbrace{360\ km}_{\text{Distance}} * \underbrace{0{,}01\ {}^{kg}/_{pcs}}_{\text{Weight of Steel Scrap}} * \underbrace{\left(5{,}071E^{-}05\ {}^{kgCO2e}/_{kgkm}\right)}_{\text{PCF Well-to-Wheel lorry}} = 1{,}8E^{-}04\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- Steel Scrap is produced by the cutting and forming process.
- PCF Well-To-Wheel lorry data can be requested from the transport operator or taken from secondary database, refer to Catena-X PCF Rulebook section 5.2.3.1.
- Transport box weight is not included.

Quality Control & Packing Electricity

$$PCF\ packing = \underbrace{0{,}026\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} * \underbrace{\left(\frac{1}{(1-2\%)}\right)}_{\text{Scrap Factor}} = 0{,}016\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- The packing process generates 2% process scrap in this example.
- The finished forged part is subjected to a quality check in this process step and packaged in plastic film.

Packaging Material Waste Treatment

$$PCF\ packaging\ waste = \underbrace{0{,}01\ kg}_{\text{Weight of Foil Waste}} * \left(\underbrace{0{,}019\ {}^{kgCO2e}/_{kg}}_{\text{PCF Logistic}} + \underbrace{1{,}087\ {}^{kgCO2e}/_{kg}}_{\text{PCF Incineration}}\right) = 0{,}011\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- PCF Logistic calculation analogue to PCF Steel Scrap Transport.
- PCF incineration data is coming from secondary database.

Required Formulas for Own Production “Finishing” (Process 2)

In the following, we come to formulas for calculating values that are required for the formulas of the PCF calculation of your Own Production Process 2:

PCF Electricity	“Blast Cleaning“ Electricity per piece	Washing & Rust Protection Electricity	Washing & Rust Protection Gas	Quality Control & Packing Electricity

PCF Electricity

$$PCF\ electricity = \underbrace{0{,}8}_{\text{80\% Residual mix}} * \underbrace{0{,}725\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Residual mix, incl. losses}} + \underbrace{0{,}1}_{\text{10\% PV}} * \underbrace{0{,}056\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from PV, incl. losses}} + \underbrace{0{,}1}_{\text{10\% Wind}} * \underbrace{0{,}01\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Wind offshore, incl. losses}} = 0{,}587\ {}^{kgCO2e}/_{kWh}$$

NOTE: Required Data: Mix of energy carriers and emission factors of the individual energy sources

“Blast Cleaning“ Electricity per piece

$$Electricity\ per\ piece = \underbrace{2{,}6\ {}^{kg}/_{pcs}}_{\text{Weight of the workpiece}} * \underbrace{0{,}015\ {}^{kWh}/_{kg}}_{\text{Electricity per kg}} = 0{,}039\ {}^{kWh}/_{pcs}$$

NOTE: The data for this process step comes from the FRED tool.

Washing & Rust Protection Electricity

$$Electricity\ per\ piece = \underbrace{2{,}59\ {}^{kg}/_{pcs}}_{\text{Weight of the workpiece}} * \underbrace{0{,}02\ {}^{kWh}/_{kg}}_{\text{Electricity per kg}} = 0{,}052\ {}^{kWh}/_{pcs}$$

NOTE: The data for this process step comes from the FRED tool.

Washing & Rust Protection Gas Energy

$$Gas\ energy\ per\ piece = \underbrace{2{,}59\ {}^{kg}/_{pcs}}_{\text{Weight of the workpiece}} * \underbrace{0{,}04\ {}^{kWh}/_{kg}}_{\text{Gas Energy per kg}} = 0{,}104\ {}^{kWh}/_{pcs}$$

NOTE: The data for this process step comes from the FRED tool.

Quality Control & Packing Electricity

$$Electricity\ per\ piece = \underbrace{2{,}59\ {}^{kg}/_{pcs}}_{\text{Weight of the workpiece}} * \underbrace{0{,}01\ {}^{kWh}/_{kg}}_{\text{Electricity per kg}} = 0{,}026\ {}^{kWh}/_{pcs}$$

NOTE: The data for this process step comes from the FRED tool.

PCF Own Production “Finishing” Process 2

0,104 $^{kgCO2e}/_{pcs}$ = “Blast Cleaning“ Electricity + Washing & Rust Protection Energy + Steel Scrap Transport 2 + Quality Control & Packing Electricity + Packaging Material Waste Treatment

PCF Upstream Formulas

For the calculation of the **Upstream PCF**, there are several **key points** to keep in mind:

- Request data from suppliers for upstream processes.
- Include emissions from the transport of materials to your factory gate if responsible.

PCF Upstream = Rod Steel + Packaging Material

Rod Steel	$Upstream\ PCF\ rod\ steel = \underbrace{3{,}2\ ^{kg}/_{pcs}}_{\text{Deployed Weight}} * \left(\underbrace{2{,}379\ ^{kgCO2e}/_{kg}}_{\text{PCF Rod Steel}} + \underbrace{0{,}032\ ^{kgCO2e}/_{kg}}_{\text{PCF Logistic \& PCF Packing}}\right) * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 7{,}851\ ^{kgCO2e}/_{pcs}$ **NOTE:** The PCF for Rod Steel and PCF Logistic & Packing is coming from the supplier.
Packaging Material	$Upstream\ PCF\ packaging\ material = \underbrace{0{,}2\ ^{kg}/_{pcs}}_{\text{Deployed Weight}} * \left(\underbrace{0{,}65\ ^{kgCO2e}/_{kg}}_{\text{PCF Packaging Material}} + \underbrace{0{,}02\ ^{kgCO2e}/_{kg}}_{\text{PCF Logistic \& PCF Packing}}\right) * \underbrace{\left(\frac{1}{(1-2\%)}\right)}_{\text{Scrap Factor}} = 0{,}137\ ^{kgCO2e}/_{pcs}$ **NOTE:** The PCF for Packaging Material and Logistic & Packing is coming from the supplier.

PCF Upstream

$7{,}990\ ^{kgCO2e}/_{pcs}$ = Rod Steel + Packaging Material

PCF Cradle-to-Gate of the finished Forged Part

The PCF of the finished Forged Part is calculated from the sum of the previous Upstream PCF and Own Production PCF. The outbound transport of the Forged Part to the customer is not included in the Cradle-to-Gate PCF.

PCF Cradle-to-Gate = PCF Upstream + PCF Own Production

$10{,}064\ ^{kgCO2e}/_{pcs} = 7{,}990\ ^{kgCO2e}/_{pcs} + 1{,}971\ ^{kgCO2e}/_{pcs} + 0{,}104\ ^{kgCO2e}/_{pcs}$

$10{,}064\ ^{kgCO2e}/_{pcs} = 7{,}990\ ^{kgCO2e}/_{pcs} + 2{,}074\ ^{kgCO2e}/_{pcs}$

PCF Contribution of Steel Scrap Transport 2

The amount of Steel Scrap for transporting to recycling from PCF Own Production Process 2 was estimated, based on industry averages. According to the screening analysis the Steel Scrap Transport 2 share is 0,002%, so that you are allowed to cut it off from the final assessment (cut-off approach, see section 4.3 in the Catena-X PCF Rulebook).

Relevance of Steel Scrap Transport 2	$PCF\ contribution\ of\ steel\ scrap\ transport\ 2 = \frac{\overbrace{1{,}8E^{-04}\ ^{kgCO2e}/_{pcs}}^{\text{PCF Steel Scrap Transport 2}}}{\underbrace{10{,}064\ ^{kgCO2e}/_{pcs}}_{\text{PCF Cradle-to-Gate}}} = 0{,}002\%$

If we calculate the proportions of all PCF shares, we get the following breakdown. According to the cut-off rules, we can exclude material or energy flows from the final assessment if they are found to be insignificant, i.e. if their combined contribution to the total PCF is less than 3%.

Final PCF Cradle-to-Gate with cut-off

PCF Upstream

		78,03%		1,36%
$7{,}990\ {}^{kgCO2e}/_{pcs}$	=	Rod Steel	+	Packaging Material

PCF Own Production "Forging" (Process 1)

		0,32%		10,87%		0,29%		7,99%		0,109%
$1{,}971\ {}^{kgCO2e}/_{pcs}$	=	"Cutting" Electricity	+	"Heating" Electricity Induction 1250°C	+	"Forming" Electricity Screw Press	+	"Tempering" Energy Gas Furnace	+	~~Steel Scrap Transport 1~~

PCF Own Production "Finishing" (Process 2)

		0,23%		0,535%		0,002%		0,154%		0,110%
$0{,}104\ {}^{kgCO2e}/_{pcs}$	=	"Blast Cleaning" Electricity	+	Washing & Rust Protection Energy	+	~~Steel Scrap Transport 2~~	+	Quality Control & Packing Electricity	+	~~Packaging Material Waste Treatment~~

PCF Cradle-to-Gate

$$10{,}042\ {}^{kgCO2e}/_{pcs} = 7{,}990\ {}^{kgCO2e}/_{pcs} + 2{,}052\ {}^{kgCO2e}/_{pcs}$$

NOTE:

In our example, the values of the crossed-out PCF shares are so low that they fall under the cut-off criteria and are considered insignificant as they have an almost negligible impact on the overall PCF. According to Catena-X PCF Rulebook, a maximum cut-off of 3% is allowed (see section 4.3). In general, the cut-off is used for material or energy flows that require a significant amount of effort for data collection but have only a minor impact on the product's overall PCF.

PCF coverage with cut-off	$$\textit{PCF coverage with cut-off} = \frac{\overbrace{10{,}042\ {}^{kgCO2e}/_{pcs}}^{\text{PCF Cradle-to-Gate with cut-off}}}{\underbrace{10{,}064\ {}^{kgCO2e}/_{pcs}}_{\text{PCF Cradle-to-Gate}}} = 99{,}78\%$$

In principle, this calculation can be used as a basis for further PCF calculations.

2.2.3 Example 3: Additive-manufactured Damper Fork

To illustrate the calculation of a PCF, we use the example of an additive-manufactured Damper Fork for cars. **Figure 4** shows an illustration of relevant processes to produce the Damper Fork. The declared unit of this PCF is 1 piece Damper Fork with a net weight of 1,21 kg. The damper fork is manufactured using laser beam melting (LBM), with 18 pieces produced per batch.

Process illustration for an additive-manufactured damper fork

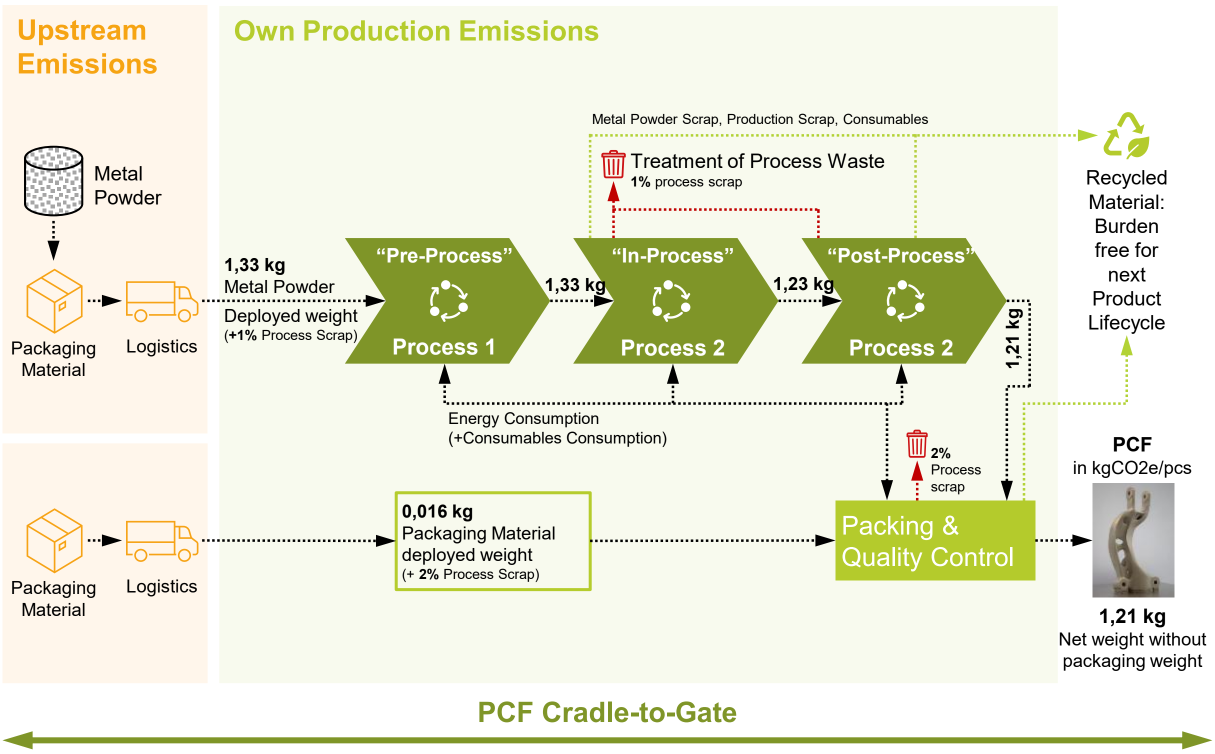

Figure 4: Processes to produce the additive-manufactured Damper Fork

NOTE:
Please note, that the GHG Emissions of the packaging are included but the declared unit refers to the mass of the unpackaged product.
This PCF calculation example refers to the Calculation of a total PCF excluding biogenic, as required for PCFs shared via Catena-X until end of 2027.

PCF Calculation Formulas

The **PCF Cradle-to-Gate** results from the sum of the **Own Production PCF** and the **Upstream PCF**.

PCF Cradle-to-Gate = **PCF Own Production** + **PCF Upstream**

NOTE:
The outbound transport of the Damper Fork is under the control of the customer receiving it. Therefore, it is not included in the cradle-to-gate PCF.

NOTE:
This example is based on a Study[6] from VDI Zentrum Ressourceneffizienz.

➔ The following formulas are an example of how to apply the rules.

[6] Bierdel et. all (2019). Ökologische und ökonomische Bewertung des Ressourcenaufwands: Additive Fertigungsverfahren in der industriellen Produktion. VDI Zentrum Ressourceneffizienz.

PCF Own Production Formulas

PCF Own Production = "Pre-Process" (Process 1) + "In-Process" (Process 2) + "Post-Process" (Process 3)

In this example, the formula for calculating the **PCF Own Production** consists of several values, each of which must be calculated using a separate formula. **In the following we lead through the calculation process for Process 1 – 3.**

PCF Own Production "Pre-Process" (Process 1)

The Pre-Process is needed to prepare the machine for the LBM process (e.g. calibrating the machine, applying the first layer of powder, flooding the machine with inert gas, heating the build platform etc.).

PCF Own Production Process 1 = "Pre-Process" Electricity

The formulas for calculating the values highlighted in gray can be found below.

"Pre-Process" Electricity

$$PCF\ Pre\text{-}Process = \left(\underbrace{0{,}68\,{}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} + \underbrace{0{,}194\,{}^{kWh}/_{pcs}}_{\text{Electricity for compressed air}}\right) * 0{,}587\,{}^{kgCO2e}/_{kWh} = 0{,}513\,{}^{kgCO2e}/_{pcs}$$

NOTE:
- Includes the electricity for the machine and electricity for compressed air.

Required Formulas for Own Production "Pre-Process" (Process 1)

In the following, we come to formulas for calculating values that are required for the formulas of the PCF calculation of your Own Production Process 1:

PCF Electricity | Electricity For Compres-sed Air

PCF Electricity

$$PCF\ electricity = \underbrace{0{,}8}_{\text{80\% Residual mix}} * \underbrace{0{,}725\,{}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Residual mix, incl. losses}} + \underbrace{0{,}1}_{\text{10\% PV}} * \underbrace{0{,}056\,{}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from PV, incl. losses}} + \underbrace{0{,}1}_{\text{10\% Wind}} * \underbrace{0{,}01\,{}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Wind offshore, incl. losses}} = 0{,}587\,{}^{kgCO2e}/_{kWh}$$

NOTE: Required Data: Mix of energy carriers and emission factors of the individual energy sources

Electricity for Compres-sed Air

$$Electricity\ compressed\ air = \underbrace{1{,}62\,{}^{m^3}/_{pcs}}_{\text{Compressed Air per piece}} * \underbrace{0{,}12\,{}^{kWh}/_{m^3}}_{\text{Electricity consumption per m}^3} = 0{,}194\,{}^{kWh}/_{pcs}$$

NOTE: The electricity consumption per 1 m³ compressed air is assumed based on industry averages.

PCF Own Production “Pre-Process” (Process 1)

$0{,}513\ {}^{kgCO2e}/_{pcs}$ = “Pre-Process” Electricity

PCF Own Production “In-Process” (Process 2)

During the “In-Process”, the individual structures are built up layer by layer by melting the powder with a laser.

PCF Own Production Process 2 = “In-Process” Electricity + Cooling Water Consumption + Metal Powder Scrap Transport 1

The formulas for calculating the values highlighted in gray can be found on later pages.

“In-Process” Electricity

$$PCF\ In\text{-}Process = \Big(\underbrace{36{,}95\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity Exposure Time}} + \underbrace{2{,}56\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity Coating Time}} + \underbrace{22{,}079\ {}^{kWh}/_{pcs}}_{\text{Electricity for compressed air}}\Big) * \underbrace{0{,}587\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 36{,}493\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- The “In-Process” generates 1% process scrap in this example.
- Measured energy consumption for exposure ratio (exposure time * laser power) and coating ratio (coating time * power consumption).

Cooling Water Consumption

$$PCF\ cooling\ water = \underbrace{1{,}09\ {}^{m^3}/_{pcs}}_{\text{Amount of Water}} * \underbrace{3{,}3E^{-04}\ {}^{m^3}/_{pcs}}_{\text{PCF Cooling Water}} * \underbrace{\frac{1000\ kg}{m^3}}_{\text{Conversion Factor}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}363\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- Measured cooling water consumption for the additive-manufacturing process.
- PCF Water is taken from secondary database.

Metal Powder Scrap Transport 1

$$PCF\ metal\ powder\ scrap\ transport = \underbrace{300\ km}_{\text{Distance}} * \underbrace{0{,}100\ {}^{kg}/_{pcs}}_{\text{Weight of Metal Powder Scrap}} * \underbrace{\left(5{,}071E^{-05}\ {}^{kgCO2e}/_{kgkm}\right)}_{\text{PCF Well-to-Wheel lorry}} = 0{,}002\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- Metal Powder Scrap of the additive manufacturing process.
- PCF Well-To-Wheel lorry data can be requested from the transport operator or taken from secondary database, refer to Catena-X PCF Rulebook section 5.2.3.1.
- Transport box weight is not included.

Required Formulas for Own Production “In-Process” (Process 2)

In the following, we come to formulas for calculating values that are required for the formulas of the PCF calculation of your Own Production Process 2:

PCF Electricity | Electricity For Compressed Air

PCF Electricity

$$PCF\ electricity = \underbrace{0{,}8}_{\text{80\% Residual mix}} * \underbrace{0{,}725\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Residual mix, incl. losses}} + \underbrace{0{,}1}_{\text{10\% PV}} * \underbrace{0{,}056\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from PV, incl. losses}} + \underbrace{0{,}1}_{\text{10\% Wind}} * \underbrace{0{,}01\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Wind offshore, incl. losses}} = 0{,}587\ {}^{kgCO2e}/_{kWh}$$

NOTE: Required Data: Mix of energy carriers and emission factors of the individual energy sources

Electricity for Compres-sed Air

$$Electricity\ compressed\ air = \underbrace{183{,}99\ {}^{m^3}/_{pcs}}_{\text{Compressed Air per piece}} * \underbrace{0{,}12\ {}^{kWh}/_{m^3}}_{\text{Electricity consumption per m³}} = 22{,}079\ {}^{kWh}/_{pcs}$$

NOTE: The electricity consumption per 1 m³ compressed air is assumed based on industry averages.

PCF Own Production “In-Process” (Process 2)

36,858 $^{kgCO2e}/_{pcs}$ = “In-Process” Electricity + Cooling Water Consum-ption + Metal Powder Scrap Transport 1

PCF Own Production “Post-Process” (Process 3)

The “Post-Process” includes the heat treatment and the removal of the support structures (In this exam-ple, the removal of support structures is a manual process).

PCF Own Production Process 3 = “Heat Treatment” Energy Gas Furnace + Metal Powder Scrap Transport 2 + Quality Control & Packing Electricity + Packaging Material Waste Treatment

The formulas for calculating the values highlighted in gray can be found on later pages.

“Heat Treatment” Energy Gas Furnace

$$PCF\ heat\ treatment = \underbrace{0{,}08\ {}^{kWh}/_{pcs}}_{\text{Amount of Gas Energy}} * \underbrace{0{,}221\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Gas}} * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 0{,}018\ {}^{kgCO2e}/_{pcs}$$

NOTE:

- The “Post-Process” generates 1% process scrap in this example.
- Measured amount of gas for the heat treatment.

Metal Powder Scrap Transport 2

$$PCF\ metal\ powder\ scrap\ transport = \underbrace{300\ km}_{\text{Distance}} * \underbrace{0{,}02\ {}^{kg}/_{pcs}}_{\text{Weight of Metal Powder Scrap}} * \underbrace{\left(5{,}071E^{-}05\ {}^{kgCO2e}/_{kgkm}\right)}_{\text{PCF Well-to-Wheel lorry}} = 3{,}04E^{-}04\ {}^{kgCO2e}/_{pcs}$$

NOTE:

- Metal powder scrap from removal of support structures.
- process PCF Well-To-Wheel lorry data can be requested from the transport operator or taken from secondary database, refer to Catena-X PCF Rulebook section 5.2.3.1.
- Transport box weight is not included.

Quality Control & Packing Electricity

$$PCF\ packing = \underbrace{0{,}012\ {}^{kWh}/_{pcs}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} * \underbrace{\left(\frac{1}{(1-2\%)}\right)}_{\text{Scrap Factor}} = 0{,}007\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- The packing process generates 2% process scrap in this example.
- The finished damper fork is subjected to a quality check in this process step and packaged in plastic film.

Packaging Material Waste Treatment

$$PCF\ packaging\ waste = \underbrace{0{,}005\ kg}_{\text{Weight of Foil Waste}} * \left(\underbrace{0{,}016\ {}^{kgCO2e}/_{kg}}_{\text{PCF Logistic}} + \underbrace{1{,}087\ {}^{kgCO2e}/_{kg}}_{\text{PCF Incineration}}\right) = 0{,}006\ {}^{kgCO2e}/_{pcs}$$

NOTE:
- PCF Logistic calculation analogue to PCF Metal Powder Transport.
- PCF incineration data is coming from secondary database.

Required Formulas for Own Production “Post-Process” (Process 3)

In the following, we come to formulas for calculating values that are required for the formulas of the PCF calculation of your Own Production Process 3:

PCF Electricity | Quality Control Packing Electricity

PCF Electricity

$$PCF\ electricity = \underbrace{0{,}8}_{\text{80\% Residual mix}} * \underbrace{0{,}725\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Residual mix, incl. losses}} + \underbrace{0{,}1}_{\text{10\% PV}} * \underbrace{0{,}056\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from PV, incl. losses}} + \underbrace{0{,}1}_{\text{10\% Wind}} * \underbrace{0{,}01\ {}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity from Wind offshore, incl. losses}} = 0{,}587\ {}^{kgCO2e}/_{kWh}$$

NOTE: Required Data: Mix of energy carriers and emission factors of the individual energy sources

Quality Control & Packing Electricity

$$Electricity\ per\ piece = \underbrace{1{,}22\ {}^{kg}/_{pcs}}_{\text{Weight of the workpiece}} * \underbrace{0{,}01\ {}^{kWh}/_{kg}}_{\text{Electricity per kg}} = 0{,}026\ {}^{kWh}/_{pcs}$$

NOTE: The data for this process step comes from the FRED tool (see Example 2).

PCF Own Production “Post-Process” (Process 3)

$$0{,}031\ {}^{kgCO2e}/_{pcs} = \text{“Heat Treatment” Energy Gas Furnace} + \text{Metal Powder Scrap Transport 2} + \text{Quality Control \& Packing Electricity} + \text{Packaging Material Waste Treatment}$$

PCF Upstream Formulas

For the calculation of the **Upstream PCF**, there are several **key points** to keep in mind:

- Request data from suppliers for upstream processes.
- Include emissions from the transport of materials to your factory gate if responsible.

PCF Upstream = Metal Powder (AlSi10Mg) + Packaging Material

The formula for calculating the value highlighted in gray can be found below.

Metal Powder (AlSi10Mg)

$$Upstream\ PCF\ metal\ powder = \underbrace{1{,}33\,{}^{kg}/_{pcs}}_{\text{Deployed Weight}} * \left(\underbrace{16{,}435\,{}^{kgCO2e}/_{kg}}_{\text{PCF Metal Powder}} + \underbrace{0{,}026\,{}^{kgCO2e}/_{kg}}_{\text{PCF Logistic \& PCF Packing}}\right) * \underbrace{\left(\frac{1}{(1-1\%)}\right)}_{\text{Scrap Factor}} = 22{,}115\,{}^{kgCO2e}/_{pcs}$$

NOTE: The PCF for Metal Powder and PCF Logistic & Packing is coming from the supplier.

Packaging Material

$$Upstream\ PCF\ packaging\ material = \underbrace{0{,}12\,{}^{kg}/_{pcs}}_{\text{Deployed Weight}} * \left(\underbrace{0{,}7\,{}^{kgCO2e}/_{kg}}_{\text{PCF Packaging Material}} + \underbrace{0{,}02\,{}^{kgCO2e}/_{kg}}_{\text{PCF Logistic \& PCF Packing}}\right) * \underbrace{\left(\frac{1}{(1-2\%)}\right)}_{\text{Scrap Factor}} = 0{,}088\,{}^{kgCO2e}/_{pcs}$$

NOTE: The PCF for Packaging Material and Logistic & Packing is coming from the supplier.

Required Formulas for PCF Upstream

Formulas for calculating values for the PCF Upstream Calculation (if it's not provided by the supplier):

PCF Metal Powder (AlSi10Mg)

$$PCF\ metal\ powder =$$

$$\underbrace{1{,}0873\,{}^{kg}/_{kg}}_{\text{Deployed Weight}} * \underbrace{9{,}89\,{}^{kgCO2e}/_{kg}}_{\text{PCF Aluminium}} + \underbrace{0{,}121\,{}^{kgl}/_{kg}}_{\text{Deployed Weight}} * \underbrace{10{,}5\,{}^{kgCO2e}/_{kg}}_{\text{PCF Silicon}} + \underbrace{0{,}0036\,{}^{kg}/_{pcs}}_{\text{Deployed Weight}} * \underbrace{27{,}92\,{}^{kgCO2e}/_{kg}}_{\text{PCF Magnesium}}$$

$$+ \underbrace{2{,}17\,{}^{kg}/_{kg}}_{\text{Deployed weight}} * \underbrace{1{,}25\,{}^{kgCO2e}/_{m^3}}_{\text{PCF Argon}} + \underbrace{2{,}722\,{}^{kWh}/_{kg}}_{\text{Amount of Electricity}} * \underbrace{0{,}587\,{}^{kgCO2e}/_{kWh}}_{\text{PCF Electricity}} = 16{,}435\,{}^{kgCO2e}/_{kg}$$

NOTE:
- The PCF for Metal Powder is coming from the supplier.
- The PCFs of the input materials of the Metal Powder are coming from secondary database.

PCF Upstream

$22{,}203\ {}^{kgCO2e}/_{pcs}$ = Metal Powder (AlSi10Mg) + Packaging Material

PCF Cradle-to-Gate of the finished Damper Fork

The PCF of the finished Damper Fork is calculated from the sum of the previous Upstream PCF and Own Production PCF. The outbound transport of the Damper Fork to the customer is not included in the Cradle-to-Gate PCF.

PCF Cradle-to-Gate = PCF Upstream + PCF Own Production

$$59{,}605\ ^{kgCO2e}/_{pcs} = 22{,}203\ ^{kgCO2e}/_{pcs} + 0{,}513\ ^{kgCO2e}/_{pcs} + 36{,}858\ ^{kgCO2e}/_{pcs} + 0{,}031\ ^{kgCO2e}/_{pcs}$$

$$59{,}605\ ^{kgCO2e}/_{pcs} = 22{,}203\ ^{kgCO2e}/_{pcs} + 37{,}402\ ^{kgCO2e}/_{pcs}$$

PCF Contribution of Quality Control & Packing Electricity

The amount of Electricity for Quality Control & Packing was estimated, based on industry averages. According to the screening analysis the share of this process is 0,012%, so that you are allowed to cut it off from the final assessment (cut-off approach, see section 4.3 in the Catena-X PCF Rulebook).

Relevance of Quality Control & Packing Electricity

PCF Quality Control & Packing Electricity

$$PCF\ contribution\ of\ quality\ control\ \&\ packing = \frac{0{,}007\ ^{kgCO2e}/_{pcs}}{59{,}605\ ^{kgCO2e}/_{pcs}} = 0{,}012\%$$

PCF Cradle-to-Gate

If we calculate the proportions of all PCF shares, we get the following breakdown. According to the cut-off rules, we can exclude material or energy flows from the final assessment if they are found to be insignificant, i.e. if their combined contribution to the total PCF is less than 3%.

Final PCF Cradle-to-Gate with cut-off

PCF Upstream

$22{,}203\ ^{kgCO2e}/_{pcs}$ = Metal Powder (AlSi10Mg) + Packaging Material

37,10%	0,15%
Metal Powder (AlSi10Mg)	Packaging Material

PCF Own Production "Pre-Process" (Process 1)

$0{,}513\ ^{kgCO2e}/_{pcs}$ = "Pre-Process" Electricity

0,86%
"Pre-Process" Electricity

PCF Own Production "In-Process" (Process 2)

$23{,}776\ ^{kgCO2e}/_{pcs}$ = "In-Process" Electricity + Cooling Water Consumption + ~~Metal Powder Scrap Transport 1~~

61,23%	0,61%	0,0026%
"In-Process" Electricity	Cooling Water Consum-ption	~~Metal Powder Scrap Transport 1~~

PCF Own Production "Post-Process" (Process 3)

$0{,}031\ ^{kgCO2e}/_{pcs}$ = "Heat Treatment" Energy Gas Furnace + ~~Metal Powder Scrap Transport 2~~ + ~~Quality Control & Packing Electricity~~ + ~~Packaging Material Waste Treatment~~

0,03%	0,0005%	0,012%	0,009%
"Heat Treat-ment" Energy Gas Furnace	~~Metal Powder Scrap Transport 2~~	~~Quality Control & Packing Electricity~~	~~Packaging Material Waste Treatment~~

PCF Cradle-to-Gate with cut-off

$$59{,}590\ ^{kgCO2e}/_{pcs} = 22{,}203\ ^{kgCO2e}/_{pcs} + 37{,}387\ ^{kgCO2e}/_{pcs}$$

NOTE:
In our example, the values of the crossed-out PCF shares are so low that they fall under the cut-off criteria and are considered insignificant as they have an almost negligible impact on the overall PCF. According to Catena-X PCF Rulebook, a maximum cut-off of 3% is allowed (see section 4.3). In general, the cut-off is used for material or energy flows that require a significant amount of effort for data collection but have only a minor impact on the product's overall PCF.

PCF coverage with cut-off

$$PCF\ coverage\ with\ cut\text{-}off = \frac{\overbrace{59{,}590\ {}^{kgCO2e}/_{pcs}}^{\text{PCF Cradle-to-Gate with cut-off}}}{\underbrace{59{,}605\ {}^{kgCO2e}/_{pcs}}_{\text{PCF Cradle-to-Gate}}} = 99{,}98\%$$

In principle, this calculation can be used as a basis for further PCF calculations.

2.2.4 Results and Findings

The PCF calculation involves meticulous data collection and collaboration with suppliers. Using Catena-X can streamline this process by providing a standardized framework for data exchange and collaboration.

Links

Catena-X PCF Rulebook v4.0	Catena-X Standard Library	Catena-X Campus	VDA LCA Inventory

3 Additional Guidance for process subdivision, system expansion and allocation of emissions

The previous chapter describes the PCF calculation, if the processes and production system match the product system. However, in practice different products share production spaces, machines and processes sequentially or even in parallel. Processes and their emissions have to be cut in sequences, emissions of not subdividable process might have to be allocated and common “overhead” such as building related heating or cooling emissions may be apportioned to all products manufactured within those buildings.

3.1 General approach in own production

Measurement infrastructure and topology are generally designed for billing purposes or, at best, for managing and reducing energy consumption, not for PCF calculation. This creates the fundamental challenge that the spatial and temporal boundaries of the measurement infrastructure do not align with those of the product system. When accounting for manufacturing facilities that produce more than one product, multiple products inevitably pass through a single meter (for energy and/or material consumption). In Life Cycle Assessment, this phenomenon is addressed as a multi-output process (Catena-X PCF Rulebook, Chapter 5, "Multi-Output Allocation Decision Procedure"). The procedure is as follows:

1. **Process subdivision:** For example, breaking down the installation of meters to the level at which the manufacturing process of a product can be measured individually in terms of space and time (the main focus of Factory-X).
2. **System Expansion:** This is only applicable when producing two products with different purposes within a single process, and when there is a clear distinction between the primary and secondary product. This scenario is so rare in discrete manufacturing that it is not discussed in detail here.
3. **Allocation: Economic and Physical**
   Does not apply to products manufactured in independent processes, even if they are produced on the same machines and in the same facilities. It also does not apply to processes where there is no clear co-product
   a) **Economic Allocation:** If there is a critical difference in value between products, the Catena-X PCF Rulebook with a 1:5 threshold must be followed.
   b) **Physical Allocation:** This rule applies to all other cases and is the norm for assigning material and energy consumption to individual products in manufacturing facilities that produce more than one product. This rule particularly applies to building emissions or idle-state emissions, but not exclusively. To improve comparability between the Product Carbon Footprints (PCFs) of the same products from different manufacturers, allocation keys are defined for all common manufacturing methods.

The choice of approach always depends on two factors: the diversity of the processes across the products passing through, and the available measurement topology (data availability). A high degree of process diversity (e.g., some parts are coated while others are heat-treated) generally justifies measurement at a fine level, down to the individual machine. Low diversity (e.g., two variants of the same product on the same line) may allow facility-level data to be divided by output count, provided a screening analysis confirms this simplification does not exceed the 3% cut-off threshold.

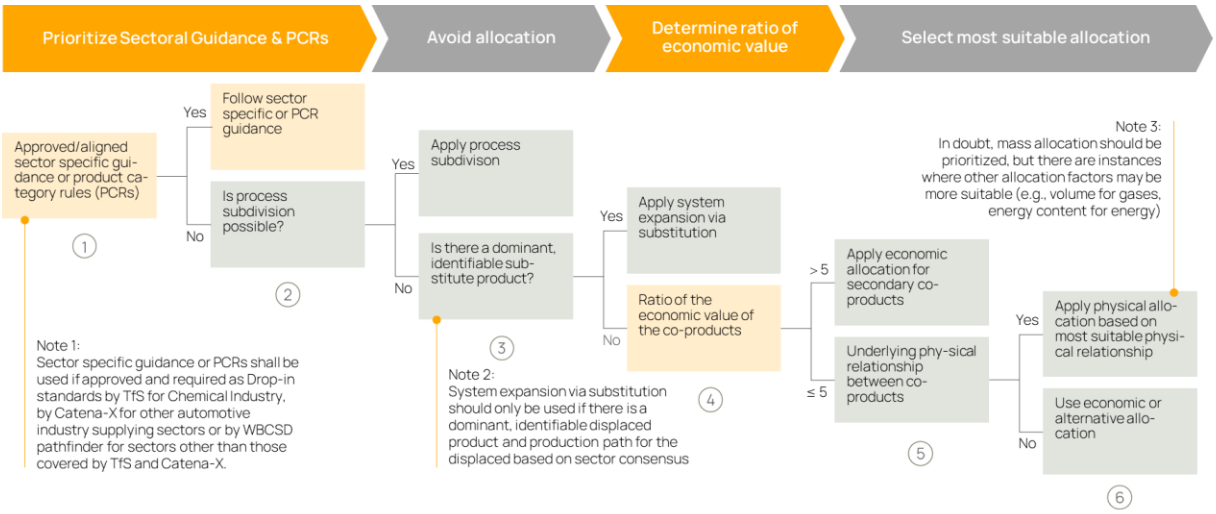

Figure 5: Multi-output allocation decision procedure (Catena-X PCF Rulebook, chapter 5)

3.2 Process subdivision

3.2.1 Purpose and Guiding Principle

In the context of Product Carbon Footprint calculation for discrete manufacturing, **process subdivision** is the act of structuring the measurement and accounting of manufacturing activities into clearly defined, individually traceable units, each representing one discrete step in the transformation of raw materials into a finished product. The fundamental objective is to align the boundaries of consumption observation with the boundaries of the product-specific manufacturing process, so that the energy and resource consumption attributed to a product reflects its actual production rather than a statistical share of a larger shared pool (avoiding allocation).

Process subdivision is not merely a technical convenience. It is the primary mechanism for elevating the data quality of own-production emissions from generic, facility-level averages to product-specific primary data, which is the highest tier, recognized under the Catena-X PCF Rulebook V4.0. Every move toward subdivision is a move toward a PCF that more rigorously reflects the environmental impact of making a specific part, rather than the environmental average of an entire plant.

3.2.2 The Root Challenge: Misaligned Boundaries

Manufacturing facilities are designed and instrumented for operational and billing purposes, not for product-level carbon accounting. Metering infrastructure is typically installed at the level of site supply points, distribution boards, or, at best, production halls. Production planning systems organize work in terms of orders, batches, and scheduling windows. These two perspectives (the metrological and the operational) rarely align naturally with the boundaries of a product's manufacturing process.

The consequence is a **multi-output process problem**: a single measurement point observes consumption from multiple products, processes, or time periods simultaneously. When this happens, it becomes impossible to read off the consumption for a specific product directly. Instead, the total observed consumption must be divided among all the products and processes sharing the measurement boundary, an exercise in allocation that introduces statistical approximation and reduces comparability between manufacturers.

Process subdivision addresses this problem at its source by moving measurement boundaries closer to the product-specific process boundary. Rather than accepting that multiple products share a meter and then apportioning the total, the goal is to instrument and track in a way that each product's consumption can be directly observed. The closer this ideal is approached, the smaller the role allocation needs to play, and the higher the quality and comparability of the resulting PCF.

It is important to recognize that full process subdivision (where a single measurement captures consumption for a single product during its entire processing window) is an ideal rather than a universal starting point. Most manufacturers will begin with partial subdivision and progressively improve granularity. The framework in this chapter is designed to guide that progression in a principled way.

3.2.3 Two Dimensions of Subdivision

Process subdivision operates along two independent dimensions, which may be pursued separately or together depending on the available measurement infrastructure and operational context.

3.2.3.1 Spatial Subdivision

Spatial subdivision means that the measurement infrastructure distinguishes between different physical locations, machines, or production areas within the facility. When a facility operates with only a single main meter, all energy consumed anywhere in the building is summed into one figure, and no spatial distinction is possible. Installing additional sub-meters on individual machines, production cells, or zones is the act of spatial subdivision.

The benefit of spatial subdivision is that it separates the consumption of different machines and therefore of different product families or process types from one another. A machining center consumes energy in a fundamentally different profile from an induction hardening station, a washing system, or a packaging line. When these are all measured together, every product is assigned a blend of these profiles regardless of which processes it actually underwent. Spatial subdivision eliminates this blending effect.

The significance of spatial subdivision scales with the **diversity of processes** within the shared measurement zone. When all products in a facility undergo essentially the same processes on the same machines, spatial subdivision offers limited benefit: the profiles are already similar, and the allocation error from treating them together is small. When different product families undergo radically different manufacturing steps, spatial subdivision becomes indispensable: a product that requires only turning and milling should not carry any share of the energy consumed by heat treatment equipment it never passes through.

A practical implication of this principle is that the installation of sub-meters should be prioritized by process diversity, not simply by machine count or facility size. A single sub-meter that separates a high-energy thermal process from the rest of a facility may deliver more improvement in PCF accuracy than a dozen meters separating broadly similar machining operations.

3.2.3.2 Temporal Subdivision

Temporal subdivision means that the measurement infrastructure distinguishes between different points in time within a machine's or process area's operation. Specifically, it means attributing consumption to the time window during which a particular product was being processed. Even when spatial subdivision has been achieved and each machine has its own meter, the machine processes different products at different times. Without temporal resolution, the total daily or weekly consumption of the machine must still be divided among all the products it processed, using piece count, processing time, or some other allocation key.

Temporal subdivision goes further: it uses the actual timestamps of production operations to extract, from the continuous consumption record, exactly the energy consumed during each product's processing window. The product is charged with the consumption measured during its specific start-to-end interval, not with a proportional share of an aggregate total. In practice, this can be achieved using scanner events at the start of a process or process chain.

The benefit is significant. Machine power demand varies considerably across its operational modes: active cutting or forming, tool changes, idle running, warm-up, and standby all draw different amounts of energy. A heavy roughing cut draws far more power than a finishing pass on the same machine. When individual production order timestamps are available alongside a fine-grained consumption time series, the PCF calculation can recover this variation and assign it correctly to the relevant product. Without temporal subdivision, all products processed on the machine receive the same average consumption per unit, regardless of the actual complexity or duration of their processing.

3.2.4 The Role of the Bill of Process

The structural foundation of process subdivision (regardless of the IT environment in which it is implemented) is the **Bill of Process (BOP)**. Where a Bill of Materials defines what a product is made of, the BOP defines how it is made: the ordered sequence of manufacturing operations required to transform input materials into the finished product.
For process subdivision purposes, the BOP serves three essential functions:

1. **Defining the sequence and boundaries of each production step.** Each entry in the BOP represents one discrete operation. Together, the BOP entries describe the complete manufacturing pathway of the product, from first process to last. This decomposition is the foundation upon which all consumption attribution is built.
2. **Connecting each operation to a specific production resource.** Each BOP entry references the machine, tool, or work center responsible for carrying out the operation. This connection enables the attribution logic to know which measurement point's data is relevant for each operation.
3. **Providing the temporal anchor for each operation.** Each BOP entry carries planned start and end timestamps, which serve as the initial estimate of when the operation occurs. When actual execution data is available (from a machine controller, an execution system, or manual recording) these planned times are replaced or supplemented by actuals, enabling precise temporal extraction from the consumption record.

A key implication is that **master data quality is a prerequisite for process subdivision quality**. If the BOP is incomplete (if operations are missing, resource references are incorrect, or time windows are systematically misaligned with actual production) the attribution of consumption will be correspondingly incomplete or inaccurate. Improving process subdivision therefore begins not with metering investments, but with an honest assessment of whether the production routing data is fit for purpose.

3.2.5 Non-Productive Time and Shared Overhead

Even when spatial and temporal subdivision are fully implemented at the machine level, a portion of consumption will remain that cannot be attributed to any specific product through direct measurement. This includes:

- **Machine non-productive time:** energy consumed during set-up, tool changes, warm-up, idle running between orders, and scheduled maintenance. These periods are not associated with any active production operation but represent real consumption that the facility incurs.
- **Facility overhead (apportioned emissions):** energy consumed for heating, cooling, ventilation, lighting, compressed air distribution, and internal transport. These services benefit all production in the facility but cannot be connected to individual products through direct measurement.

The principle governing these shared consumption categories is that **they must be apportioned, not ignored**. Further details on allocation can be found in chapter 3.3.

3.2.6 Proportionality: When to Subdivide and When to Allocate

Process subdivision is not an unconditional obligation at all levels of granularity. The effort required to install, maintain, and validate additional measurement infrastructure must be weighed against the improvement in PCF accuracy that the investment delivers.
High-energy processes require subdivision. Processes that dominate the own-production PCF (typically those involving significant thermal energy input, high-power machining, or extended cycle times) must be individually measured and attributed. The potential error from allocating these processes rather than subdividing them is large enough that it will make allocation an inadequate substitute.

Low-contribution processes may be handled by allocation. Auxiliary operations such as part marking, final visual inspection, or minor handling steps typically contribute so little to the total own-production PCF that a screening analysis will confirm their share falls below the cut-off threshold. For these processes, the effort of installing dedicated measurement infrastructure is disproportionate to the accuracy benefit, and a well-chosen allocation key is a fully legitimate approach.
The practical consequence is that process subdivision should be pursued with **selective depth rather than uniform breadth**. The goal is not to meter every machine and every operation, but to identify the small number of processes that account for the dominant share of own-production emissions and to ensure that these are measured individually. This focused approach delivers most of the accuracy benefit of full subdivision at a fraction of the implementation cost.
A structured screening analysis, in which all operations in the BOP are assigned a preliminary energy consumption estimate and ranked by their contribution to the total, is the appropriate tool for making these prioritization decisions. The output of such a screening is a clear picture of which processes require subdivision, which may be handled by allocation, and which are candidates for cut-off entirely. This analysis should be revisited whenever the production mix, process configuration, or metering infrastructure changes significantly.

3.2.7 Iterative Implementation: A Maturity Path

Process subdivision is not a binary state that a facility either has or lacks. It is a capability that can be developed incrementally, with each step delivering measurable improvements in PCF data quality. Understanding this iterative nature is essential for planning realistic improvement roadmaps.
A useful way to think about the maturity path is in terms of the **level at which consumption is attributed:**

Table 1: Maturity level in Process Subdivision

Maturity Level	Spatial Boundary	Temporal Boundary	Residual Allocation Needed
Facility level	Whole site or building	Annual or periodic average	Across all products and processes
Hall level	Production zone or hall	Shift or day	Across product families in the zone
Machine level	Individual machine	Shift or production run	Across products processed on the machine
Order level	Individual machine	Specific production order	Non-productive time and overhead only

Each step up this ladder eliminates a layer of allocation and replaces it with direct observation. The transition from facility level to hall level is often achievable by analyzing existing metering topology and identifying meters that are already spatially aligned with individual production zones. The transition from hall level to machine level typically requires additional sub-metering investments, prioritized on the basis of the energy significance screening described above. The transition from machine level to order level additionally requires production execution data (timestamps that connect consumption records to specific production orders) which may come from a planning or execution system, from manual records, or from machine controller data.
The important practical insight is that **each level of subdivision can be deployed independently for different processes**. A facility does not need to achieve order-level subdivision for every machine before any process subdivision delivers benefit. A single high-energy process brought from facility-level allocation to machine-level or order-level measurement may account for a large fraction of the total PCF improvement opportunity. Companies should identify their highest-impact subdivision opportunities, act on those first, and progressively extend subdivision depth as resources and data availability permit.
This maturity-path perspective also makes the relationship between process subdivision and data quality concrete. Primary, product-specific data (the highest quality tier) is what process subdivision produces. Every step up the maturity ladder improves the specificity, credibility, and comparability of the reported PCF. This is the essential value proposition of process subdivision, and it is why the approach

is positioned as the preferred first step in the multi-output allocation decision procedure ahead of system expansion and allocation.

3.3 Allocation of process emissions according to physical parameters

The following section illustrates the basic procedure using energy as an example. Physical allocations can be applied from the plant level down to the machine level. This procedure applies to all consumption types for which approach 1-3a, shown in Figure 5, is not applicable.

Whether data is collected at the site, hall, or machine level (process subdivision) and where allocation takes place always depends on:

- The diversity of the processes and how they vary for the products passing through, and
- the measurement topology (data availability at different levels of granularity).

Examples:

- A high degree of diversity generally justifies measurement at a low level (in extreme cases, down to the machine). One example of high diversity is when some manufactured parts are only coated while others must first be tempered in an oven.
- Low diversity exists when two similar vehicle types run on the same production line and undergo the same manufacturing steps. In this case, it is sufficient to record the total energy consumption of the facilities and divide it by the number of vehicles produced in order to calculate the emissions from in-house manufacturing on a per-vehicle basis. To validate this simplification, the process that contributes the most significantly to the footprint and differs the most should undergo a screening analysis (CX-PCF Rulebook Version 4, section 4.3.1). If the emissions delta combined with other process variations will be 3% or more of the product's total footprint, the process must be assessed individually.
- The lack of consumption meters at the machine or plant level necessitates a lower level of "Process Subdivision". If this results in unacceptable deviations during screening analysis, then representative consumption values must be remeasured manually.

NOTE:
While a fine-grained measurement topology theoretically offers the most options, it does not always justify the additional data collection and validation effort. Many data points complicate validation and increase the risk of systematic errors (e.g., a meter that fails silently and reports zero consumption). The level of subdivision should be proportionate to the significance of the process for the overall PCF.

3.3.1 Allocation units and allocation keys

There are several approaches for distributing shared emissions fairly and transparently across individual products. The overall emissions of a facility or process must be apportioned to individual products or production processes using an allocation key that is both appropriate and practically implementable.

The main allocation methods are:

- **Energy consumption-based allocation:** If detailed consumption data are available, emissions are distributed according to the energy consumed per machine or per production area.
  Allocation key = energy consumed for Product A / total energy consumption
- **Quantity-based allocation:** Emissions are distributed proportionally to a physical output quantity (number of pieces, volume, mass) of the product (e.g., for heating, lighting).
  Allocation key = quantity of Product A / total production quantity

- **Area-based allocation:** When a building hosts several production lines or products, emissions (e.g., air conditioning, heating, lighting) can be apportioned by occupied floor area.
  Allocation key = floor area used for Product A / total floor area
- **Time-based allocation:** If certain products remain longer in the production process, the usage duration of machines or building services can be used as the allocation factor (e.g., for compressed air demand, air conditioning).
  Allocation key = operating hours for Product A / total operating hours
- **Economic allocation:** Emissions are apportioned by the revenue, market value, or margin of the individual products. To be applied only where the economic value ratio exceeds 5:1 (per CX-PCF Rulebook section 5.1.2).
  Allocation key = economic value of Product A / economic value of all products in the process step
- **Hybrid methods:** Combinations of the above allocation methods, e.g., area-based for spatial overheads combined with time-based for machine-specific loads.

If no product category rules (PCR) or sector-specific guidance exist, standards recommend allocating emissions based on physical properties (e.g., energy consumption, area, mass, time) or economic criteria (e.g., market price). Where multiple allocation methods are applicable, ISO 14067 requires a sensitivity analysis to demonstrate the impact of the chosen approach. The selected method must be documented to ensure transparency and comparability.

In summary, there is no single "best" method, the right choice depends on the system boundaries, the characteristics of the production site (which data are available at what level of granularity), and the properties of the manufactured products (size, complexity, process duration):

- Energy-based: Most precise for energy-intensive products (industries with high energy costs)
- Quantity/mass-based: Best for material-intensive production (e.g., metalworking)
- Economic allocation: Appropriate only when the economic value ratio exceeds the 5:1 threshold
- Hybrid methods (e.g., time-based combined with area): Suitable for products with long production or throughput times

3.3.2 Allocation keys for facility overhead (apportioned emissions)

In discrete manufacturing, a significant share of emissions arises from shared facility services (same concept as overhead cost) that cannot be identified as part of a single discrete manufacturing step for a specific product but have to be “apportioned” as part of the manufacturing environment. Relevant apportioned emissions include:

- Heating and cooling of production halls
- Air conditioning and ventilation (including cleanroom conditions)
- Water and hot water supply
- Lighting
- Compressed air generation and distribution
- Internal transport vehicles and cranes (fuel or electric)
- Storage and warehouse emissions

These apportioned emissions must be collected at the facility level and then allocated to individual products using an appropriate allocation key, as described in section 3.3.1. The allocation key should reflect the physical driver of the emission as closely as possible.

3.3.2.1 Consideration of Storage Emissions (taken from PACT Methodology V3)

As there are no specifications concerning storage emissions addressed by Catena-X or Manufacturing-X, the best practices of the PACT Methodology V3[7] were considered. Where significant, storage-related emissions are calculated by multiplying the **percentage share of the total floor area** occupied by the reference product by the **total energy consumption of the storage facility**, which is in turn multiplied by the **emission factors of the various energy sources** used at the site (see formula below).

$$GHG\ emissions_{storage} = \frac{Area_{product}}{Area_{storage\ site}} * Energy\ consumption_{site} * Emission\ factor_{energy\ type}$$

3.3.3 Allocation keys for different manufacturing processes

In order to allocate multi-output process emissions an allocation keys must be selected. The challenge is to find an allocation key, which reflects why the burden arises. The criteria should be: if product A is produced more, the burden of the shared process should increase proportionally. If a variety of processes is covered by the same allocation, a common denominator has to be found for these processes or products among which the emissions are being allocated.
DIN 8580[8] provides a sound basis because it enables clear classification of manufacturing processes into main groups, groups, and subgroups, facilitating consistent communication and description. Figure 6 shows the six main groups of the DIN 8580.

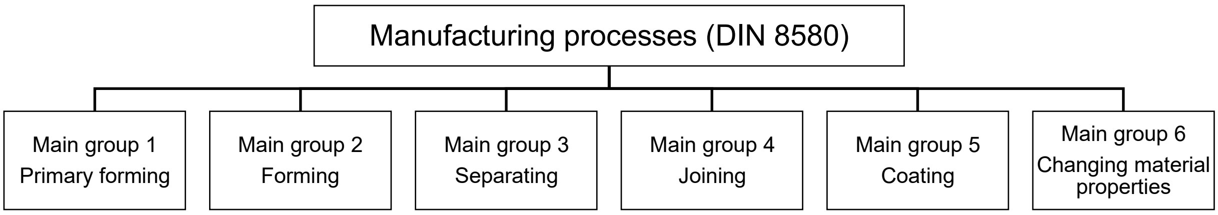

Figure 6: Manufacturing processes, main groups (DIN 8580)

To simplify the selection of an allocation key, Table 2 – Table 7 list likely physical properties for different process categories for each main group according to DIN 8580.

Note:
The following examples are illustrative and must be adapted to the actual process layout, measurement topology, and data availability. The goal is to define robust and practical allocation units for typical process groups through which energy and, where applicable, material consumption can be attributed to products.

Table 2: Primary forming

Group	Subgroup (examples)	Allocation key
Primary shaping from a liquid state	Die casting	Mass × heat capacity × ΔT (energy required in Ws)
Primary shaping from a plastic state	Extrusion	Mass × heat capacity × ΔT
Primary shaping from a pulpy state	Casting of concrete, plaster	Mass or volume
Primary shaping from a granular/powdery state	Pressing	Mass × heat capacity × ΔT

[7] WBCSD PACT, "PACT Methodology V3: Methodology for Calculating and Exchanging Cradle-to-Gate Product Carbon Footprints (PCFs)," Version 3.0, April 30, 2025 (last updated December 2025). [Online]. Available: https://www.carbon-transparency.org/resources/pact-methodology-v3
[8] DIN Deutsches Institut für Normung, "DIN 8580:2022-12 - Fertigungsverfahren - Begriffe, Einteilung," Deutsches Institut für Normung e.V., Berlin, December 2022.

Group	Subgroup (examples)	Allocation key
Primary shaping from a chip or fibrous state	Production of paper and cardboard	Mass
Primary shaping from a gaseous/vaporous state	Vapor deposition in a mold	Mass × heat capacity × ΔT
Primary shaping from an ionized state	Electrolytic deposition in a mold	Mass × ionization energy

Table 3: Forming (DIN 8582)

Group	Subgroup (examples)	Allocation key
Compressive forming (DIN 8583-1)	Rolling; open-die forging	Mass × heat capacity × ΔT, or mass × number of forming steps; tensile strength
Tenso-compressive forming (DIN 8584-1)	Deep drawing; hydroforming	Mass × heat capacity × ΔT (hot/cold); tensile strength
Tensile forming (DIN 8585-1)	Stretch reducing	Mass × heat capacity × ΔT (hot/cold); tensile strength
Bend forming (DIN 8586)	Bending with linear tool movement	Mass × heat capacity × ΔT (hot/cold); tensile strength
Shear forming (DIN 8587)	Displacement by shear with linear tool movement	Mass × heat capacity × ΔT (hot/cold); tensile strength

Table 4: Separating (DIN 8588–8589)

Group	Subgroup (examples)	Allocation key
Severing (DIN 8588)	Shear cutting	Length × thickness × shear strength
Geometrically defined cutting (DIN 8589-0)	Turning; drilling; milling	Material removed × (processing time / tool life)
Geometrically undefined cutting (DIN 8589-0)	Grinding with rotating tool; belt grinding	Material removed × (processing time / tool life)
Removal operations (DIN 8590)	Thermal cutting, laser cutting	Time, or material removed (at constant power, using standard conversion values from tables)
Disassembling (DIN 8591)	Disassembly; desoldering	Thermal treatment time, or disassembly time when low energy is used
Cleaning (DIN 8592)	Blast cleaning	Surface area (m²), supplemented by time if processing times vary significantly across surfaces

Table 5: Joining (DIN 8593-0)

Group	Subgroup (examples)	Allocation key
Compounding (DIN 8593-1)	Laying, placing, layering	Time
Filling (DIN 8593-2)	Filling	Volume (l) for filling; surface area (m²) for soaking and impregnation
Pressing in/on (DIN 8593-3)	Screwing	Number of joints
Joining by primary forming (DIN 8593-4)	Pouring	Volume (l) × heat capacity × ΔT; exception electroplating: volume of layer only (thickness × area)
Joining by shaping (DIN 8593-5)	Riveting	Mass of rivets, or mass × heat capacity × ΔT for hot/cold forming

Group	Subgroup (examples)	Allocation key
Joining by welding (DIN 8593-6)	Fusion welding	Weld length (identical parameters); otherwise material, gas, energy, and time
Joining by soldering (DIN 8593-7)	Soft soldering; hard soldering	Number of solder joints (e.g., electronic), or mass × avg. heat capacity × ΔT for larger joints
Glueing (DIN 8593-8)	Bonding with physically curing adhesives	Surface area (m^2)
Textile joining	—	Number, length (m), or area (m^2)

Table 6: Coating (DIN 8580, Group 5)

Group	Subgroup (examples)	Allocation key
Coating from a liquid state	Hot-dip coating; painting, varnishing	Surface area (m^2)
Coating from a plastic state	Filling	Number of coating passes × surface area (m^2)
Coating from a paste-like state	Plastering, rendering	Number of passes × surface area (m^2)
Coating from a granular/powdery state	Thermal spray coating	Volume (surface area × layer thickness)
Coating by welding	Fusion deposition welding	Volume (surface area × layer thickness), with component heating recorded separately
Coating by brazing	Deposition soft/hard soldering	Volume (surface area × layer thickness) × temperature difference
Coating from a gaseous/vaporous state (vacuum)	Vacuum deposition	Volume (surface area × layer thickness)
Coating from an ionized state	Galvanic coating	Volume (surface area × layer thickness)

Table 7: Changing material properties (DIN 8580, Group 6)

Group	Subgroup (examples)	Allocation key
Strain hardening	Strain hardening by forging	Mass × heat capacity × ΔT; tensile strength for surface hardening via radiation (m^2)
Heat treatment	Annealing; hardening; tempering; age hardening	Mass × heat capacity × ΔT
Thermo-mechanical treatment	Ausforming	Mass × heat capacity × ΔT × time (depending on material and component shape)
Sintering, firing	—	Mass × heat capacity × ΔT × time (depending on material and shape)
Magnetization	—	Volume
Irradiation	—	Irradiation time
Photochemical processes	Exposure	Exposure time

3.4 Practical Examples

The following four worked examples demonstrate the practical application of process subdivision and allocation in discrete manufacturing contexts. Each example includes the specific situation, the recommended approach, and a numerical illustration where applicable.

3.4.1 Example A: Temporal process segregation

Situation
A CNC machining center processes three different part numbers (Part A, Part B, Part C) sequentially during a single production shift. The machine is connected to a single energy meter at the machine control cabinet, which records total energy consumption continuously at 15-minute intervals. No additional sub-metering per product exists.

Approach
Temporal process segregation uses the high-resolution time-stamped energy data from the machine control system (or an IoT energy logger) to attribute energy consumption to each product based on the exact time windows during which that product was being processed. This is the preferred approach because it avoids allocation entirely, each product is charged only with the energy consumed during its own processing window, including the proportional share of non-productive time (e.g., the set-up time for that product's batch) (see Figure 7 below).

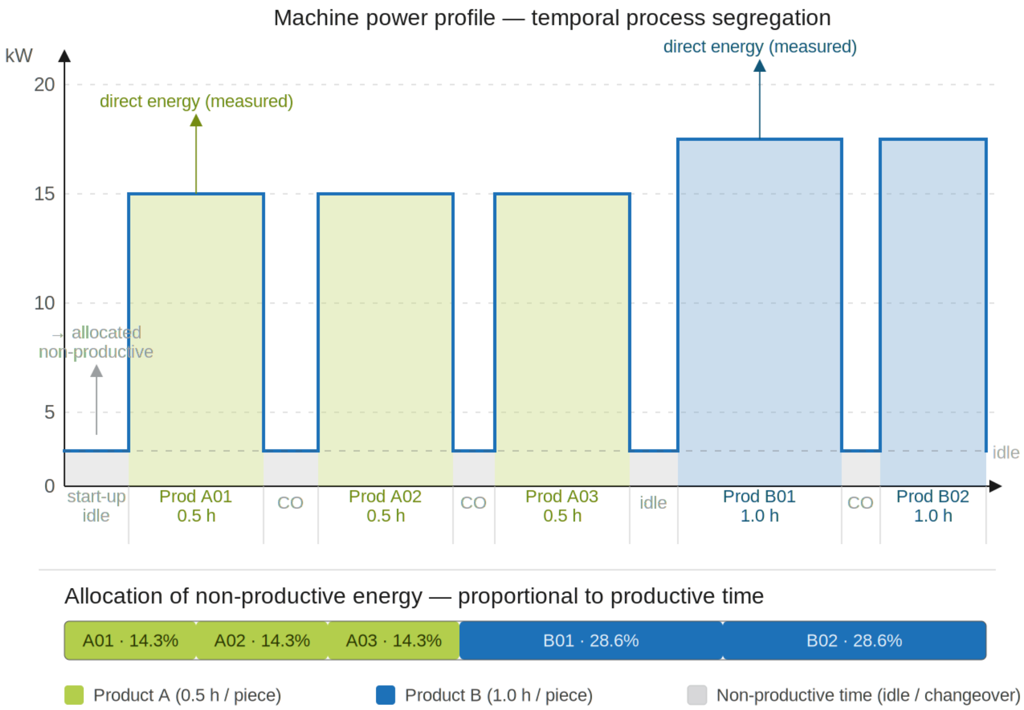

Figure 7: Schematic machine power profile illustrating temporal process segregation.

Energy consumed during each productive window (green: Product A, blue: Product B) is measured directly and attributed to that product. Non-productive time energy is allocated proportionally to productive time share (allocation bar, bottom).

Data requirements:

- Machine energy log with timestamp and consumption in kWh (e.g., at 1-minute or 15-minute resolution)
- Production log with start and end timestamps per product / production order
- Number of pieces produced per order

Calculation (numerical example):
The machine operates for a total of 8 hours (480 min) during the shift. Energy consumption logged at 15-minute intervals totals 48,0 kWh over the shift. The production log records:

Table 8: Calculation (numerical example)

Product	Processing window	Duration (min)	Pieces produced	Measured energy in window (kWh)
Part A	06:00 – 07:30	90	45	9,0
Part B	07:30 – 09:00	90	20	9,5
Part C	09:00 – 11:30	150	60	15,0
Non-productive (set-up, idle)	Various	150	—	14,5
Total	**—**	**480**	**125**	**48,0**

Non-productive time (14.5 kWh) is allocated to the three products in proportion to their productive processing time:

Table 9: Calculation (numerical example) with non-productive time.

Product	Productive time share	Non-productive energy allocated (kWh)	Total energy (kWh)	Pieces	PCF electricity contribution ($kgCO_2eq$/piece)
Part A	90 / (90+90+150) = 27,3%	14,5 × 0,273 = 3,96	9,0 + 3,96 = 12,96	45	12,96 × EF / 45
Part B	90/330 = 27,3%	14,5 × 0,273 = 3,96	9,5 + 3,96 = 13.46	20	13,46 × EF / 20
Part C	150/330 = 45,5%	14,5 × 0,455 = 6,60	15,0 + 6,60 = 21,60	60	21,60 × EF / 60

EF = Electricity emission factor ($kgCO_2eq$/kWh), e.g., residual grid mix for the country of production.

NOTE:
This approach requires that the machine control system or an IoT energy logger can provide energy consumption data at a sufficiently fine time resolution, and that the production execution system records start/end timestamps per production order. Where this data is available, temporal segregation is the most accurate and most defensible approach (it is not allocation, but direct process subdivision).

3.4.2 Example B: Spatial process segregation

Situation
A production hall contains five different machining centers, each dedicated to a different product family or process type (turning, milling, drilling, grinding, and a combined turning/milling center). Previously, all energy was measured only at the hall level via a single main meter. The company installs individual sub-meters on each machine's main supply circuit.

Approach
Spatial process segregation uses additional metering infrastructure to measure energy consumption at the individual machine or section level, making it directly attributable to the products processed on that machine. This eliminates the need for allocation between different machines or product families. Each machine's measured consumption is attributed directly to the products it processes (and, within a machine, temporal segregation or a simple piece-count allocation may be applied).

Data requirements:

- Sub-meter installed on each machine with data recorded continuously
- Production log mapping production orders to specific machines
- Number of pieces produced per order per machine

Example: Before and after sub-meter installation

Table 10: Before and after sub-meter installation

Machine	Annual consumption (kWh)	Products processed	Allocation before sub-metering (% of hall total)	Direct measurement after sub-metering (kWh)
Turning centre	42.000	Part family T	Hall total / 5 (naive)	42.000 (measured)
Milling centre	67.000	Part family M	Hall total / 5 (naive)	67.000 (measured)
Drilling centre	18.000	Part family D	Hall total / 5 (naive)	18.000 (measured)
Grinding centre	31.000	Part family G	Hall total / 5 (naive)	31.000 (measured)
Turn-mill centre	82.000	Part family TM	Hall total / 5 (naive)	82.000 (measured)
Hall total	**240.000**	—	**240.000 (hall meter)**	**240.000 (sum of sub-meters)**

In the naive allocation (no sub-meters), each product family would be assigned 240.000 / 5 = 48.000 kWh, significantly overestimating the footprint of the drilling center (48.000 vs 18.000 kWh) and underestimating the turn-mill center (48.000 vs 82.000 kWh). Sub-metering eliminates this distortion and ensures product-specific accuracy.

NOTE:
Spatial process segregation through sub-metering is the most effective way to improve data quality and primary data share in discrete manufacturing. Even where temporal segregation within a machine is not yet possible, machine-level sub-metering already removes the largest source of distortion between product families. Companies should treat the expansion of sub-metering infrastructure as a roadmap priority for PCF improvement.

3.4.3 Example C: System expansion (rare in discrete manufacturing)

Situation
System expansion is applicable when a single production process intentionally produces two outputs with different functions, and where a dominant, identifiable alternative production route for one of the outputs exists based on sector consensus. In discrete manufacturing, this situation is rare because most processes are designed to produce a single primary product, with any secondary material outputs (e.g., metal chips from machining) classified as waste rather than co-products under the CX-PCF Rulebook classification hierarchy (section 5.2.4 and Annex A1).

When system expansion might apply:
A potential case in discrete manufacturing is a combined heat and power (CHP) unit operated on site that simultaneously produces electricity (used in production) and heat (used for space heating or process heat). Both outputs have distinct, separate functions and there are well-established alternative production routes for each (grid electricity; natural gas heating). In this case, the CX-PCF Rulebook requires checking the economic value ratio between electricity and heat (section 5.1.2): if the ratio is ≤ 5, physical allocation using exergy is applied; if >5, economic allocation applies. System expansion

via substitution would require sector consensus on the displaced product and is subject to strict conditions.

General recommendation:
In the absence of explicit sector guidance or PCR that prescribes system expansion for a specific discrete manufacturing context, companies should not apply system expansion and should instead proceed directly to physical or economic allocation per the CX-PCF allocation decision tree. Attempting to apply system expansion without a clearly dominant, sector-consensus-based displaced product risks non-compliance with the Rulebook and reduces comparability.

NOTE:
System expansion is not applicable to the treatment of production scrap (e.g., metal chips, punching slugs). Pre-consumer scrap that is sent for recycling is classified as waste under the CX-PCF Rulebook and follows the cut-off approach: the waste treatment emissions are borne by the product generating the waste (polluter pays), and the scrap leaves the system boundary burden-free.

3.4.4 Example D: Allocation of building (apportioned) emissions

Situation
An assembly plant produces three product types (Product A, Product B, and Product C) within the same building. The total annual building-related emissions (electricity for lighting, HVAC, compressors, IT, intralogistics; thermal energy for heating; water) have been determined as 6.332.280 kgCO_2eq, based on the following measured consumption:

Table 11: Measured consumption and emission factors

Energy/resource type	Annual consumption	Emission factor	Emissions (kgCO_2eq)
Electricity (HVAC, lighting, compressors, IT, intralogistics)	9.000.000 kWh	0,435 kgCO_2eq/kWh	3.915.000
Thermal energy (heating)	12.000.000 kWh	0,201 kgCO_2eq/kWh	2.412.000
Water	16.000.000 l	0,00033 kgCO_2eq/l	5.280
Total building emissions	—	—	**6.332.280**

The following three allocation approaches are compared. All three are physically defensible; the choice depends on data availability and the nature of the products.

Approach D1: Allocation by number of assembled pieces (quantity-based)
This is the simplest approach and requires only the number of pieces produced per product type. It assumes each piece generates the same building footprint, which is defensible only if the products are similar in size, production time, and resource use.

Table 12: Allocation by number of assembled pieces (quantity-based)

Product	Pieces produced / year	Share (%)	Building PCF allocated (kgCO_2eq)	PCF per piece (kgCO_2eq/piece)
Product A	468	468 / 1.308 = 35,8%	6.332.280 × 0,358 = 2.265.678	2.265.678 / 468 = 4.841
Product B	790	790 / 1.308 = 60,4%	6.332.280 × 0,604 = 3.824.542	3.824.542 / 790 = 4.841
Product C	50	50 / 1.308 = 3,8%	6.332.280 × 0,038 = 242.060	242.060 / 50 = 4.841
Total	**1.308**	**100%**	**6.332.280**	—

Result: Every piece receives the same allocation (4.841 $kgCO_2eq$/piece) regardless of its actual resource use. This is only appropriate where products are genuinely similar.

Approach D2: Allocation by assembly time (time-based)
This approach uses the recorded assembly time per product type as the allocation key, reflecting the actual duration for which the building services are consumed per product. Working plans and throughput times from the production planning system are the data source.

Table 13: Allocation by assembly time (time-based)

Product	Total assembly time (h/year)	Share of production time (%)	Building PCF allocated ($kgCO_2eq$)	Pieces	PCF per piece ($kgCO_2eq$/piece)
Product A	1.033	1.033 / 4.175 = 24,8%	6.332.280 × 0,248 = 1,570,405	468	3.356
Product B	344	344 / 4.175 = 8,2%	6.332.280 × 0,082 = 519.247	790	657
Product C	2.798	2.798 / 4.175 = 67,0%	6.332.280 × 0,670 = 4.242.628	50	84.853
Total production time	4.175	100%	6.332.280	—	—
Total time incl. non-productive	8.760 h	—	—	—	—

Result: Products with longer assembly times bear a proportionally larger share of building emissions, reflecting actual usage of building services more accurately.

Approach D3: Allocation by economic value
Economic allocation should only be applied where the CX-PCF Rulebook requires it, i.e., where the ratio of the economic values of the products exceeds 5:1 (section 5.1.2). Market prices (or production costs) averaged over 3–5 years should be used.

Table 14: Allocation by economic value

Product	Avg. market price (€/piece)	Pieces / year	Economic value (€)	Share (%)	Building PCF allocated ($kgCO_2eq$)	PCF per piece ($kgCO_2eq$/piece)
Product A	300	468	140.400	140.400 / 545.400 = 26%	6.332.280 × 0,26 = 1.630.091	3.483
Product B	500	790	395.000	395.000 / 545.400 = 72%	6.332.280 × 0,72 = 4.586.084	5.805
Product C	200	50	10.000	10.000 / 545.400 = 2%	6.332.280 × 0,02 = 116.103	2.322
Total	**—**	**1.258**	**545.400**	**100%**	**6.332.280**	**—**

Economic value ratio: 500 / 300 = 1,67 ≤ 5. Therefore, per the CX-PCF Rulebook, physical allocation should be applied first (Approaches D1 or D2). Economic allocation would only be mandatory if the ratio exceeded 5.

Summary: Comparison of approaches

Table 15: Comparison of approaches

Approach	Allocation key	Data required	Specificity	CX-PCF applicability
D1 – Quantity-based	Number of pieces	Production count per product	Low – all pieces get equal allocation	Always applicable as fallback
D2 – Time-based	Assembly time per product	Working plans and throughput times	Medium-High – reflects actual building usage per product	Preferred physical approach where time data is available
D3 – Economic	Market price × quantity	3–5 year avg. prices per product	Low – driven by market, not physical use	Only if economic value ratio > 5:1

NOTE:
Building emissions should be addressed at the annual level for external PCF reporting (customer communication). For internal production optimization, shorter averaging periods (e.g., weekly) can be used to identify emission hotspots and support production planning. However, only the annual average should be communicated externally as the PCF, unless the customer can directly influence the specific batch or production conditions.

3.4.5 Example E: Allocation of non-productive time (idle, changeover, preheating)

Situation
A pharmaceutical packaging machine (demonstrator case based on the Uhlmann use case) runs for a total of 24 hours per day. During this period, it produces two product types: Product A (3 pieces, 0,5 h productive time each = 1,5 h total) and Product B (2 pieces, 1,0 h productive time each = 2,0 h total). Total productive time is therefore 3,5 h; non-productive time (idle, changeover, preheating) is 20,5 h. The machine's energy during non-productive time is 9 kWh; building emissions for the day are 3 $kgCO_2eq$.

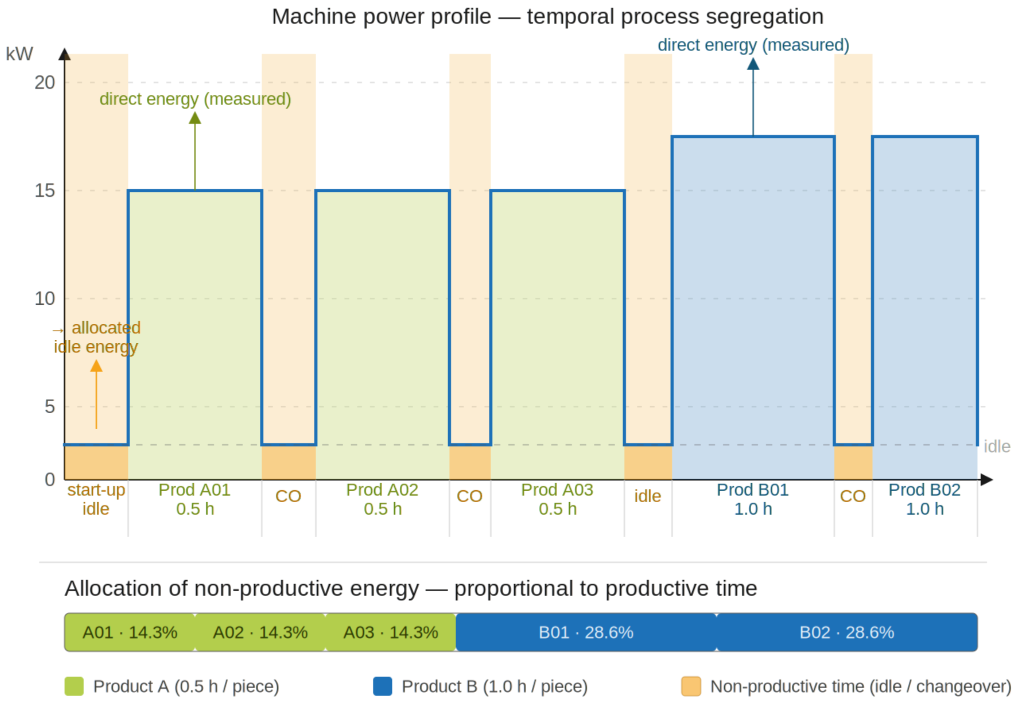

Figure 8: Machine power profile and temporal process segregation (allocation of non-productive energy proportional to productive time)

Data

Table 16: Data of Example E

Parameter	Value
Total productive time (t_p)	3,5 h
Total non-productive time (t_{np})	20,5 h
Non-productive energy (E_{np})	9 kWh
Electricity emission factor	0,32 $kgCO_2eq/kWh$
Non-productive time emissions ($PCF_{np} = E_{np} \times EF$)	2,88 $kgCO_2eq$
Building emissions ($PCF_{building}$)	3,00 $kgCO_2eq$
Total apportioned emissions ($PCF_{apportioned}$)	**5,88 $kgCO_2eq$**

Allocation of apportioned emissions by productive time share (Option 1):

Table 17: Allocation of apportioned emissions by productive time share (Option 1)

Product	Pieces produced	Total productive time (h)	Time share (%)	apportioned emissions per piece ($kgCO_2eq$/piece)
Product A	3	1.5	1,5 / 3,5 = 42,9%	(5,88 × 0,429) / 3 = 0,840
Product B	2	2.0	2,0 / 3,5 = 57,1%	(5,88 × 0,571) / 2 = 1,678

Allocation by productive time per individual piece (Option 2):

Where product-level time tracking is available (e.g., from machine data or MES), each individual piece can be assigned its own apportioned emission share based on its specific productive time:

Table 18: Allocation by productive time per individual piece (Option 2)

Product	Productive time per piece (h)	Time share per piece (%)	apportioned emissions per piece ($kgCO_2eq$/piece)
Product A (0,5 /piece)	0,5	0,5 / 3,5 = 14,3%	5,88 × 0,143 = 0,840
Product B (1,0 /piece)	1,0	1,0 / 3,5 = 28,6%	5,88 × 0,286 = 1,682

Both options produce consistent results per piece where the number of pieces and total productive time align. Option 2 is preferred where MES data provides individual piece timestamps, as it enables product-specific PCF calculation for each production order without further aggregation.

NOTE:
The same allocation principle used for non-productive time emissions should also be applied to building emissions, using productive time (or piece count, if time data is unavailable) as the common allocation key. This ensures methodological consistency across all apportioned emission categories and simplifies implementation in PCF calculation tools.

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