# Catena-X's Contribution to Sustainability in the Automotive Supply Chain

Dr. Jürgen Padberg,
Detecon International GmbH, Cologne, Germany

**Abstract.** The automotive industry finds itself in times of multidimensional transformations: Abandonment of combustion engines to transition to electrical engines for the reduction of global $CO_2$ emissions, digitalization of products, services, and value-creating processes, the collapse of supply chains due to various global crises, continued cost pressure, increasing ESG regulations, and the impending takeover by Chinese manufacturers. These societal and industry shifts are creating significant challenges for European OEMs and their suppliers. Digitalization of the value chain, enabling secure and sovereign data exchange and hence providing improved transparency, efficiency and resilience along the automotive supply chain are the objectives of the initiative Catena-X. Amongst other use cases, the improvement of sustainability is on the top of the agenda for Catena-X, namely capabilities for monitoring and reporting the Product Carbon Footprint (PCF) as well as features in the area of Circular Economy. This article gives insights into these capabilities of Catena-X. It is based on a presentation by the author at the 18th International MTZ Congress on Future Powertrains, "Powertrains and Energy Systems of Tomorrow 2024", Chemnitz, May 15th, 2024 [1].

**Keywords:** Catena-X, Sustainability, Automotive Supply Chain, PCF, Product Carbon Footprint, Circular Economy, Recycling, Digitalization, Data Spaces.

## 1 Overview on Catena-X: Data Ecosystem for the Automotive Supply Chain

### 1.1 The WHY of Catena-X: Current Challenges of the Automotive Industry

The COVID-19 pandemic, a blocked Suez Canal, and the Ukraine war have shown just how vulnerable the automotive supply chain is with its "just-in-time" and "just-in-sequence" cornerstones. Better transparency along the whole chain "from cradle to end-of-life" is needed to enable all involved parties to improve the collaboration for the sake of better effectiveness and efficiency.

Digitalization, namely the exchange of data along the whole value chain, provides a significant opportunity to build the foundations for increased transparency and hence capabilities for better planning, improved traceability, faster decision-making, increased automation and enhanced collaboration. However, data sovereignty, (cyber) security, and full control over amount and purpose of the data exchange must be ensured in order to engender trust in the data exchange mechanisms.

Catena-X aims to enable such a data exchange ecosystem for the automotive supply chain. It is an open, collaborative, and interoperable data ecosystem to enable sovereign and standardized data exchange along the automotive value chain [2] [3].

The term "Catena-X" refers to, on the one hand, the initiative founded in July 2021 as a consortium of 28 key players in the German automotive industry including OEMs, suppliers, service providers, and scientific research entities. This consortium was intended to last for three years to give birth to the ecosystem by defining standards, elaborating architectures, data models, processes, developing the first software services for data exchange, and acquiring a sufficient number of participants to allow the ecosystem to go live and grow in the years to follow. The consortium is supplemented by the Catena-X Association, where additional members can join to proceed with the consortium's mission after its termination in July 2024 [4]. Currently, the Catena-X Association has approximately 170 members from Germany, other European countries and abroad [5].

On the other hand, "Catena-X" is also used as the name for the data ecosystem itself. In this sense, Catena-X is a network of participants exchanging data along the automotive value chain in accordance with agreed-upon standards and respecting the principle of data sovereignty. It is a data space that enables data exchange but does not store the data centrally – it's neither a cloud nor a data lake. Instead, it is based upon the principles of GAIA-X [6] and one of GAIA-X's first "lighthouse projects" [7].

Supported and subsidized by the German Federal Ministry for Economic Affairs and Climate Action, Catena-X is intended to boost digital transformation and sustainability in Germany and in the EU. Although its nucleus is in Germany, the network is intended to become a global network; a first international hub has been opened in France [8] and dialogues are underway with American [9], Chinese, and other automotive associations [10].

In October 2023, the network went live with its first operating company, Cofinity-X [11]. This operating company provides the data exchange services of Catena-X, based upon the open-source software of the consortium Catena-X, published on the Tractus-X platform [12] and ensures the adherence of all participants to Catena-X's rules.

There were four major drivers for the launch of Catena-X in 2021, see Fig. 1:

1. **Resiliency**: The COVID-19 pandemic had dramatically shown that the automotive supply chain with its high sophisticated "Just-in-Time" and "Just-in-Sequence" principles is vulnerable. Breakdowns of the global supply chain, leading to factory standstills, caused multi-billion-dollar losses for the automotive industry around the globe. The "peer-to-peer" view for planning and operating the supply chain was no longer suitable to cope with global disturbances such as pandemics, wars, and the like. Transparency along the whole chain – or at least along the most relevant parts – became crucial.

2. **Sustainability and Regulatory Requirements**: New sustainability regulations have brought new obligations for the automotive industry, predominantly ESG reporting obligations, e.g. the Supply Chain Act ("Lieferkettensorgfaltspflichtengesetz") [13], PCF (Product Carbon Footprint) reporting and Circular Economy regulations ("Kreislaufwirtschaftsgesetz") [14]. These reports need data to be exchanged along

the whole supply chain, especially when the calculations are to be based upon “primary data” and not only upon assumptions and averages.

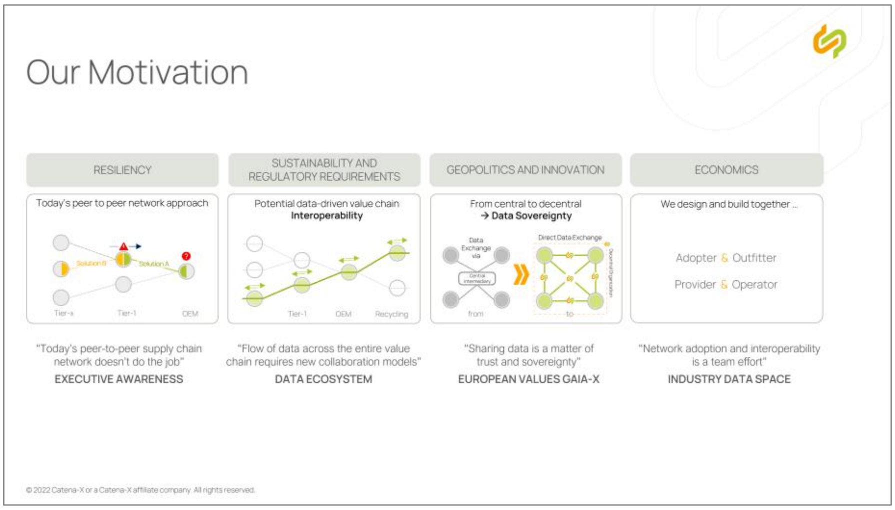


**Fig. 1.** Motivation to launch the initiative Catena-X. Source: [3].

3. **Geopolitics and Innovation**: The required exchange of data between participants within the global supply chain and the aspired transparency will mark a significant change in the relationship of the automotive industry; moving away from a strongly hierarchically driven network with the OEMs on top towards a trust-based ecosystem with partners that may decide which data will be shared, with whom, and for which purposes. Federated data governance and data sovereignty are necessary to reap the benefits of data-driven processes and organizations. For these purposes, GAIA-X was the perfect foundation [6].

4. **Economics**: Obviously, the mechanisms for the required data exchange should be built-up as future-oriented and as efficiently as possible. Hence, the initiative a priori included digital service providers as experts in the consortium and adopted the principles for Data Spaces. Detecon International and its sister company, T-Systems International, both members of group Deutsche Telekom, are such digital service providers. Detecon is officially “Qualified for offering Catena-X advisory and consulting services” and T-Systems provides several technical services for participating in the network, that have also been officially certified by Catena-X.

### 1.2 The WHAT of Catena-X: Use Cases to exploit the Business Value

The Catena-X initiative decided to start with 10 use cases that had been agreed-upon between the 28 members of the consortium and the public promotors, namely the German Federal Ministry for Economic Affairs and Climate Action. These 10 initial use cases are aiming at (see Fig. 2, from bottom to top):

- setting the foundation for data exchange
- supporting several efficiency measures for the production and logistics processes along the automotive value chain
- providing capabilities to cope with ESG regulations, namely the PCF monitoring & reporting and Circular Economy topics.

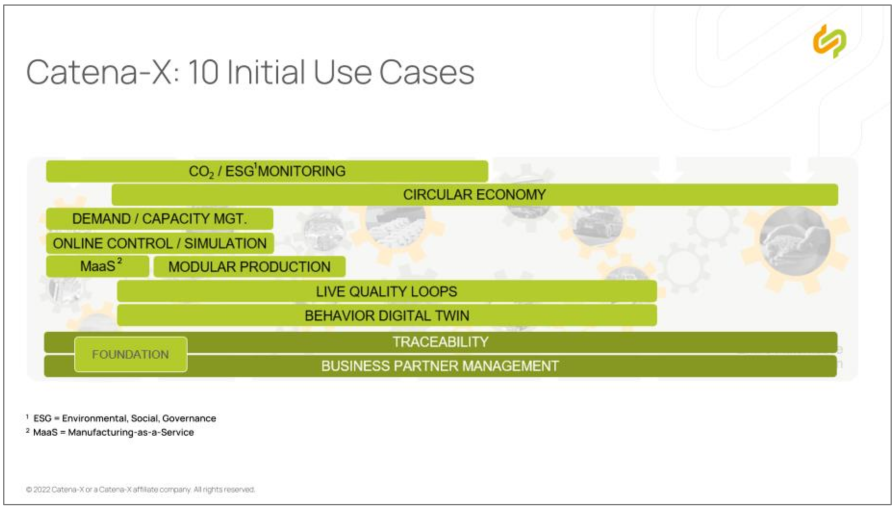


**Fig. 2.** Catena-X: 10 Initial Use Cases. Source: [3].

Currently, approximately half of these use cases have been brought to life, especially the ones at the bottom of Fig. 2 (“Foundation”) and the use cases at the top (dealing with sustainability). Some of the remaining use cases, especially the more complex ones that require more fundamental changes in the collaboration processes, are still under construction.

Further use cases may evolve over time as the network grows and new needs for data exchange along the supply chain may arise. New cases can be brought in by any of the members of the Catena-X association and will be defined within working groups.

When defining a Catena-X use case, the involved partners agree upon relevant standards, e.g. in-scope and out-of-scope, calculation schemes and relevant process flows. And they also define and agree upon the data models with mandatory and optional data fields and formats, so that the subsequent data exchange and all applications that use the data can follow the defined standards. The standards – as well as related software components – are published and made accessible as open-source components on the platform Eclipse Tractus-X™. This platform is the official open-source project in the Catena-X ecosystem under the umbrella of the Eclipse Foundation [12].

## 1.3 The HOW of Catena-X: Architecture and Data Flows

As already stated, Catena-X is a data space that enables the participants of the network to mutually exchange data according to standards that had been defined by the Catena-X consortium, respectively its successor, the Catena-X association. These standards include:

- the definition of the data objects that can be exchanged ("Digital Twins")
- the method of technical data transportation using the Catena-X platform, operated by an operating company (currently Cofinity-X, further operating companies to follow, especially in the course of internationalization).

The example in Fig. 3 illustrates the principles of Catena-X's data flows. The example covers the scenario where an OEM ("VW") wants to calculate the PCF of some recently produced vehicles and therefore requests from one of its suppliers ("BASF") the PCF of the supplied materials (e.g. paint or synthetic granules). The flow is as follows:

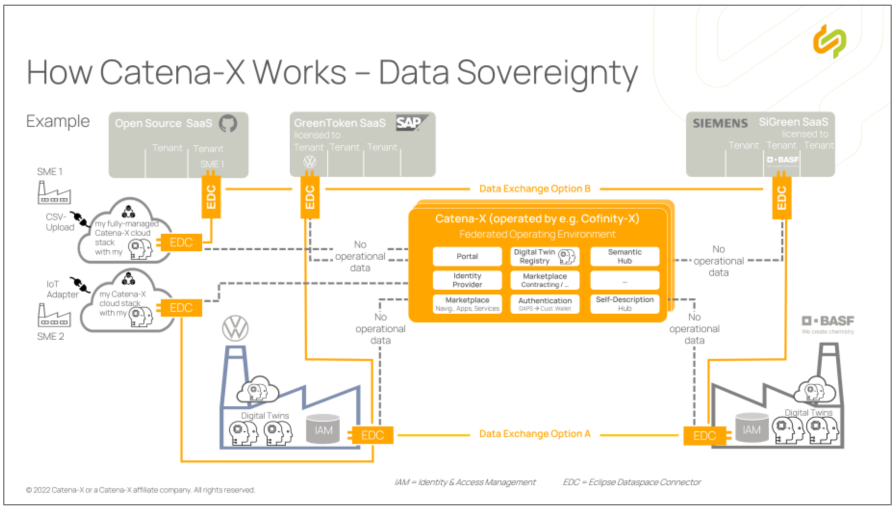


**Fig. 3.** Catena-X working principles to enable data exchange, thus granting data sovereignty. Source: [15]. Note: Meanwhile, the original concept of a centralized Digital Twin Registry has been decentralized with Catena-X Release 3.2, October 2023.

1. All stakeholders are connected via an "Eclipse Data Space Connector" EDC to the network. This a standard connector developed by Catena-X [15], granting the adherence to the agreed-upon data exchange standards that are based on GAIA-X.
2. The OEM sends a request to Catena-X (operated by e.g. Cofinity-X) to determine whether the supplier is registered at the network and whether the requested data objects have been registered in the "Digital Twin Registry".
3. If yes, Catena-X sends a request to the supplier (BASF) to check whether they are willing to provide the data to the requesting partner (VW) for the requested purpose.

4. If, and only if, the supplier agrees, Catena-X builds the data bridge between the two partners (VW and BASF) to let them exchange the PCF data using the EDCs (orange data flow). Important note: Catena-X is not involved in these operational data flows (solid orange lines), but only handles and manages the requests between the partners using non-operational data (dotted grey lines in above Fig. 3).

5. In case one or both partners use third-party providers of Catena-X Business Apps, e.g. SAP's PCF tool "GreenToken", recently rebranded to "SDX" – Sustainability Data Exchange [16] or Siemens' PCF tool "SiGreen" [17], the data exchange happens between the app providers on behalf of the registered partners. For this purpose, the app providers need to certify their tool, become part of the Catena-X network (i.e. contracting to adhere to the rules), and then provide access to the network using an EDC in their customers' "Tenant". Then, the requests from the OEM (VW) to the supplier (BASF), will be redirected by Catena-X to the app providers (dotted grey lines in above Fig. 3) and the data flow itself will happen directly between the app providers "on behalf of" their customers VW / BASF (solid orange line "Option B" in above Fig. 3). The results of the data processing (in this case the PCF report) can be accessed by using the app provider's tools, normally using an https connection.

6. In case of smaller companies ("SME") that do not have the resources to manage the data processing, the data storage ("Digital Twins") and the components for the data exchange ("EDC") on their own, certified Catena-X service providers can provide these services as "SaaS" solutions (Software as a Service) together with cloud storage compliant to Catena-X standards (see top left part in above Fig. 3).

In order to set up this infrastructure, different capabilities must be activated by all participants. The architecture as illustrated in Fig. 4 shows the different data management capabilities along the data flows from one participant to the other ("upstream") and reverse ("downstream"):

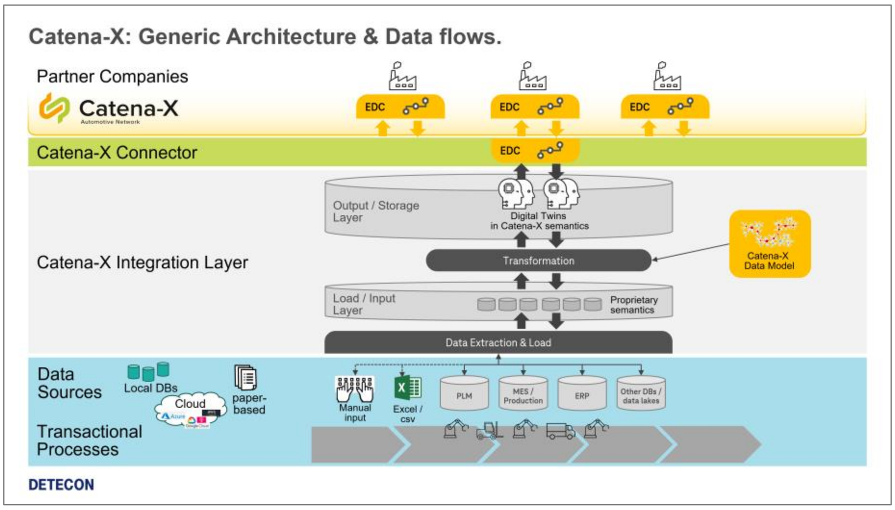


**Fig. 4.** Catena-X Generic Architecture and Data Flows. Source [1].

1. Starting at the bottom, it's always necessary to have the transactional manufacturing and logistics operational processes in mind that shall be supported by Catena-X's use cases. These differ from use case to use case, may involve two or more parties, and may require uni-directional or bi-directional data flows.

2. A vast majority of the transactional processes are supported by systems and applications, e.g. Product Lifecycle Management systems (PLM), Manufacturing Execution Systems (MES) to steer the operations on the shopfloor, Logistics Management Systems, Enterprise Resource Management systems (ERP) and multiple databases or data lakes that collect and provide data from various systems to build an aggregated view for management purposes. The applications and hence the data storage may run in local databases "on premise" or in the cloud. And – not to be neglected – a lot of data is still captured and processed in "auxiliary" tools such as Excel or even handled completely manually ("paper-based").

3. In order to compile the data objects that are required for an exchange via Catena-X – the so called "Digital Twins" – the data from the transactional systems must be extracted, transformed into the data models and formats that Catena-X has defined, and then provided in a storage layer, see the "Catena-X Integration Layer" in Fig. 4. The mechanisms are more or less the same as in classical ETL tools [18].

4. After the data has been prepared in the semantics that Catena-X has defined for the selected use case, the data is ready to be exchanged via Catena-X with Partner Companies as previously described, see Fig. 3. For this, the "Catena-X Connector", the EDC, is used [15].

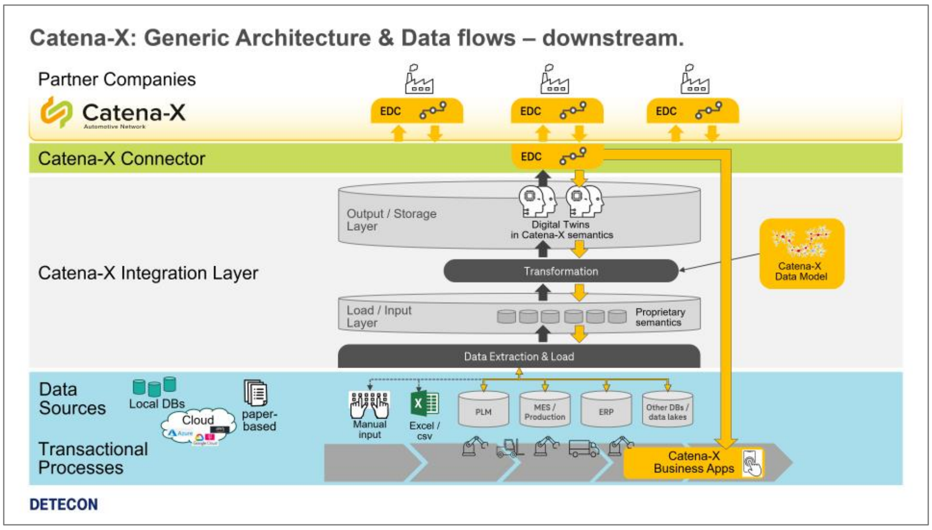


**Fig. 5.** Catena-X Generic Architecture and Data Flows – downstream. Source [1].

5. For the reverse data exchange, the "downstream", two options are available, see Fig. 5. The first option is a "reverse" upstream data flow, in which the "Catena-X

Integration Layer" capabilities are used to transform and load the data. But this time "reverse", i.e. from Catena-X data objects ("Digital Twins") to data objects that can be loaded and processed in the transactional systems that support the production processes. The second option – if available – is the use of "Catena-X Business Apps" that are provided by specialized and certified Catena-X app providers. These apps are made available to the Catena-X participants via the Cofinity-X app portal [11]. In this case, the "reverse" data processing is done by the app itself and only the result, e.g. a PCF report as a PDF document, will be used in the processes – in this case the ESG reporting process. The Catena-X community has developed many APIs / SDKs called "KITs" for different use cases that allow programmers of systems to interact with the Catena-X standards. These KITs are provided as open-source software on Catena-X's open-source platform Tractus-X [12].

# 2 Deep dive into Catena-X use case Product Carbon Footprint

The following description of the use case Product Carbon Footprint is mainly extracted from the description of this use case on the Catena-X / Tractus-X platform [19].

## 2.1 Motivation and Mission of the PCF use case

Sustainability has become increasingly important in the automotive industry in recent years. In particular, the topic of $CO_2$ emissions is the focus of interest, and the product-specific $CO_2$ footprint (PCF: Product Carbon Footprint) has developed into a key indicator for sustainable product design and supply chains. Accordingly, there is a need to determine this data as precisely as possible across the automotive supply chain and to exchange it among partners in the network. This requires appropriate standards for calculation and exchange of data.

**Vision**: Report and steer the de-carbonization of our value chain with dedicated measures based on real PCF values, without compromising upstream data sovereignty.

**Mission**: Addressing supply chain carbon emissions today is missing reliable data about baseline emissions, effect of reductions, and best practices. This is due to three reasons:

- Complexity of supply chains leading to huge amount of data: complex supply chains spanning different countries and actors from many industries lead to huge amounts of data.
- Lack of Trust: Unwillingness to share data because of risk of losing competitive advantage, because data is shared with competitors.
- Missing standards for measuring carbon emissions in a comparable way.

Catena-X's solution for PCF is addressing these challenges by working on a trustworthy ecosystem that prioritizes data sovereignty, security, and collaboration on standards. Therefore, the mission is to revolutionize the supply chain industry by providing a platform where suppliers can securely share their primary Product Carbon Footprint (PCF) data throughout the supply chain.

## 2.2 Scope and content of the PCF use case

The scope of the PCF use case is the calculation and the exchange of Product Carbon Footprint (PCF) data across the supply chain for parts / components that are already in series production ("after start of production (SOP)"). One can therefore assume that a real supply chain already exists for this part / component.

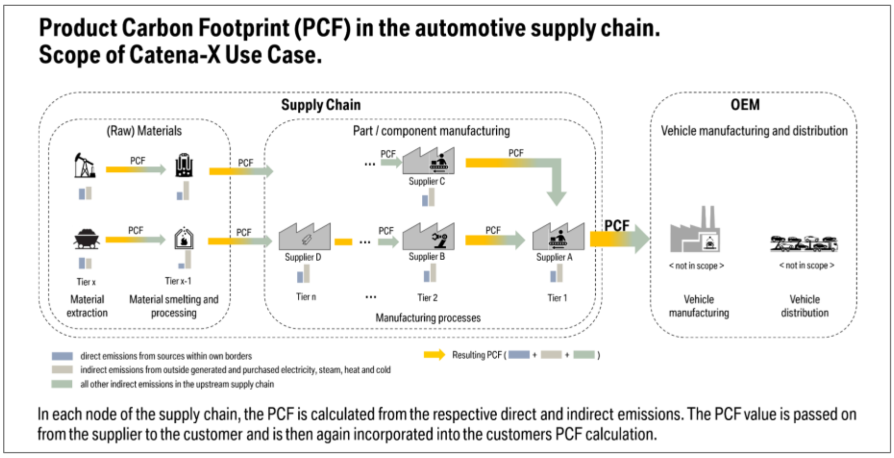


**Fig. 6.** Scope of Catena-X use Case Product Carbon Footprint (PCF). Source: [19].

In order to fulfil this scope, the Catena-X working group "PCF" defined the PCF calculation standards and the data model that is needed to mutually exchange the data along the supply chain to calculate the PCF on each layer of the value chain "from cradle to end-of-life"[1]. These standards were compiled and documented in the "Catena-X PCF Rulebook", now available in its second version [20].

The goals of the Catena-X PCF Rulebook are as follows [21]:

- Moving away from using industry average measurements towards using real emission data of the real supply chain
- Standardizing measurement and reporting along the supply chain to make $CO_2$ emission data comparable
- Definition of standardized & WBCSD[2]/Stakeholder approved $CO_2$ calculation schemes and methodologies

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1 Until now, the scope of the Catena-X use case PCF is limited to "from cradle to gate", i.e. ends at the gate of the OEM. The calculation of the PCF generated at the OEM as well as the PCF calculation for distribution to the customer, utilization of the vehicle over its lifetime and additional PCF emissions for recycling at the "end-of-life" are subject to potential updates of the Catena-X PCF Rulebook.

2 World Business Council for Sustainable Development.

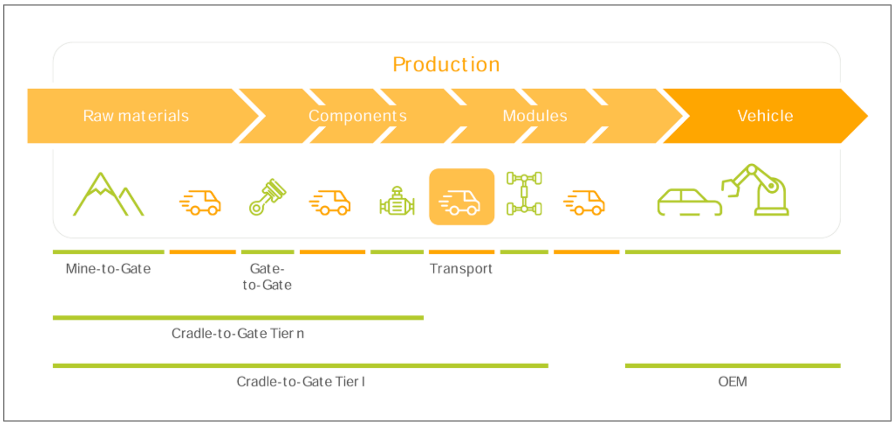


**Fig. 7.** Scope of Catena-X use Case Product Carbon Footprint (PCF). Catena-X's PCF calculation scheme aims at increasing the primary data ratio and also considers the transportation $CO_2$ footprint. Source: [20].

The data exchange process is initiated top-down (e.g., at the OEM; but it can also start at any level of the supply chain), starting with a request of a customer to the supplier. It could then be continued step-by-step throughout the entire tier-n supply chain. Ideally, the entire supply chain would be covered via this cascading request/response process. The result would be a PCF that is 100% based on requested and reported data.

In the real world, this will not be implemented this way, at least in the short and medium term. It can be assumed that this process and information chain will break down at certain points in the supply chain. There, data is not requested, but is calculated using secondary data, as is standard procedure these days. There can be various reasons for this:

- The affected part of the supply chain is only of minor relevance to the PCF; the effort required to determine the real data would therefore not be worthwhile.
- The supplier cannot or does not want to provide corresponding data.

However, it is important that a PCF value reported from a supplier to its customer always represents the entire supply chain behind it. Therefore, the following data is recorded in a PCF calculation and aggregated to form the resulting PCF:

- Direct emissions, that are generated in the supplier's own production system ("Scope 1")
- Indirect emissions from purchased energy ("Scope 2")
- Upstream emissions caused by purchased products from the upstream supply chain ("Scope 3")

The data for direct and indirect emissions will usually come from internal data sources, as these emission shares are generated in the supplier's own production system. The upstream emissions ("Scope 3") can either be requested from the respective sub-supplier. Or it could be calculated, e.g., by using information from eco-databases.

Putting this all together, the transparency on the PCF for a given part or component is created through a cascade of top-to-bottom PCF requests, and a cascade of aggregated PCF data from bottom to top.

This data along the supply chain will be exchanged using the Catena-X network. A pilot for this chain has been realized by T-Systems with its partners Ford, Flex Automotive and IBM and presented in January 2024 on the CES fair in Las Vegas [22].

## 3 Deep dive into Catena-X use case Circular Economy

The following description of the use case Circular Economy is mainly extracted from the description of this use case on the Catena-X / Tractus-X platform [23].

### 3.1 Motivation and Mission of the Circular Economy use case

The automotive industry is one of the largest consumers of raw materials, including metals, plastics, and textiles. Managing these materials sustainably and efficiently is a significant challenge, with an increasing focus on reducing waste, improving recyclability, and ensuring responsible sourcing. Traditional linear models of material consumption led to resource depletion, environmental degradation, and missed economic opportunities.

By embracing circular economy principles, automotive companies can transition to sustainable materials management, improve resource efficiency, and contribute to a greener, more resilient industry. The Circularity use case of Catena-X shall empower stakeholders to transition towards a circular economy by providing frameworks, guidelines and best practices to enhance sustainability credentials, enable data-driven decision-making and foster collaboration and innovation in the automotive industry.

The overarching goals of the Circularity KIT are to:

- Establish an understanding of requirements along circular value chains and how businesses can profit by implementing sustainable solutions.
- Offer standards and guidelines for industry stakeholders.
- Explain different circularity topics and provide tools to implement them.

**Vision**: “Closing the Loop, by harnessing the power of Circularity”. The vision is to create a future where resources are intelligently and efficiently utilized, enabling industries and communities to minimize waste, embrace R-strategies, and foster a circular economy that leads to a sustainable and prosperous world.

**Mission**: In a world facing increasing environmental pressures and resource scarcity, transitioning to a circular economy is crucial. This approach ensures responsible resource management through R-strategies, secondary material quotas, material accounting, and optimized end-of-life processes. By closing the loop on material flows, we can reduce our environmental impact, drive innovation, and create economic opportunities that secure a sustainable future.

### 3.2 Scope and content of the Circular Economy use case

The scope of Circular Economy use case currently covers five capabilities, that are put into context by the so called "Circularity KIT wheel", see Fig. 8. The five capabilities complement each other to cope with all relevant stations of a Circular Economy – from Product Design & Development over Material Planning & Sourcing, Production and Use Phase / Service / Maintenance to End-of-Life services.

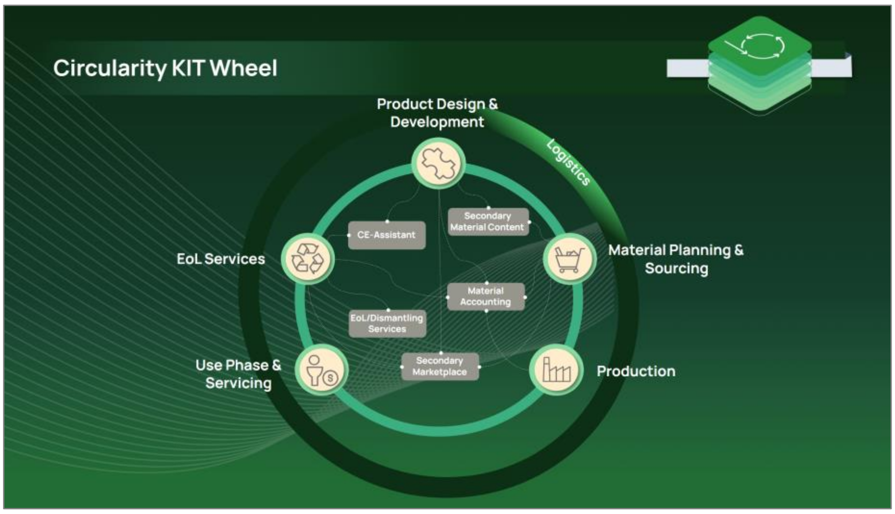


**Fig. 8.** Scope of Catena-X use Case Circular Economy. Source: [23].

In its first version, the use case covers five focus topics along an automotive value loop:

1. **Secondary Material Content**: Promotes the use of secondary materials in the automotive industry by providing a standardized data model for data exchange and a calculation framework.
2. **Material Accounting**: Provides standardized scrap/waste and secondary material data exchange for the ecosystem partners to create transparency about recycling activities and verifiable closed loops.
3. **EoL / Dismantling Services**: Offers essential support for the digitalization and automation of the End-of-Life phase to consequently close value loops.
4. **CE-Assistant (Circular Economy Strategy Assistant)**: Is a decision support system that facilitates the selection of the optimal R-Strategy for end-of-life vehicles, with a focus on Reuse, Remanufacturing, Recycling, and Recovery, guided by a comprehensive technical and environmental assessment process.
5. **Secondary Marketplace**: Buying and selling used components and secondary raw materials in order to create and open new opportunities for collaborating across the value chain and closing the loop on component and material level.

Similar to the PCF use case, one of the major contributions of Catena-X is, that the working group has defined and agreed-upon standards for the area of Circular Economy, such as how to calculate relevant KPIs, e.g. the Secondary Material Content (SMC) and the Secondary Material Quota (SMQ) and also defined and agreed upon the data models that are required for exchanging this data along the value chain. This enables a comparable and even verifiable calculation of sustainability KPIs and enables a standardized data exchange, using the data sovereignty mechanisms of Catena-X.

## 4 Summary

Catena-X has developed the standards for coping with two of the major challenges in the area of sustainability: the calculation of Product Carbon Footprint (PCF) and Circular Economy. Initially motivated by ESG reporting regulations, Catena-X capabilities go beyond the data collection, computation, and reporting tasks; they also contribute to a profound transformation in traditional automotive processes and thus in the mindset of automotive stakeholders towards more sustainable production and transportation.

The technical basis has recently been laid by the go-live of the Catena-X platform in October 2023. Now it is up to the acting stakeholders at the OEMs, suppliers, and service providers to build up a trust-based ecosystem where partners collaborate along the whole value chain instead of hiding information and act as competitors. This is a huge mindset change challenge for the whole industry. But as always: “Successful digital transformation is only 20% technology and 80% change”.

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