UNDERSTANDING THE VALUE OF DATA ECOSYSTEMS FOR CIRCULAR ECONOMY METRICS

Insights from Manufacturing-X Projects

Manufacturing-X
Guidance Board

IMPRINT

Publisher

Manufacturing-X Guidance Board

Project Office Manufacturing-X

Open Industry 4.0 Alliance Implementation GmbH
Willy-Brandt-Platz 6
81829 Munich, Germany

Version History

[July 8th, 2026 – Version 1.0 (First Release)]

Authors

Dr.-Ing. Jens Pottebaum, Paderborn University – Decide4ECO
Katrin Dietrich, Fraunhofer-Institut für Integrierte Schaltungen IIS – Fluid 4.0
Lara Schmidt, Fraunhofer-Institut für Integrierte Schaltungen IIS – Fluid 4.0
Mostafa Biglari, Trumpf
Michael-Georg Schmidt, BASF – Catena-X
Alessandro Pistillo, BASF – Chem-X
Nadja Gravina, Bergische Universität Wuppertal – Construct-X
Franziska Schmidt, Bergische Universität Wuppertal – Construct-X

DOI

10.24406/publica-9382

PART OF MANUFACTURING-X

Funded by the European Union
NextGenerationEU

Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

1 Motivation

The Circular Economy is a promising economic model for addressing future challenges such as resource scarcity, rising raw material prices, and the creation of more resilient value chains. However, the implementation of Circular Economy models often fails due to a lack of circular metrics or general difficulties in measuring the effectiveness of Circular Economy initiatives, particularly because it places high demands on horizontal and vertical data integration. Various Manufacturing-X projects have conducted initial studies to understand whether data ecosystems are an enabler to solve these challenges. These studies frame **Circular Economy metrics as a management instrument for growth, margin protection, and resilience** and not only as a requirement for compliance or sustainability reporting. This white paper gives insights into the work of these projects.

The role of Circular Economy metrics is to make the circular value of product visible and manageable. This means that products at their end-of-life are rather at their end-of-first-use with significant value remaining on serviceability as well as on product, component or material level. The literature presents a wide variety of circular metrics that enable support for both effective reporting and fundamental decision support for steering profitable circular strategies. Besides selecting and implementing circular metrics, data input is key to utilize the potential. Here, the strengths of data ecosystems promise data availability and therefore significant advantages for revenue growth through enhanced resource use, margin improvement through controlling material supply, and supply resilience by reducing dependency on volatile raw materials.

Another aspect to consider is that in Europe a bottom-up approach is taken, where individual industries define their own circular metrics (or Key Performance Indicators) and standards. This approach leads to a lower level of interoperability, when these metrics and standards have to be shared along the value chain where different industries participate. For the necessary industrial scaling of the Circular Economy, it is of particular importance that there are cross-industry agreements on metrics. The circular metrics need to be backed by shared data models in a way, that the data needed can be collected and passed on automatically. Efficient standardization is meant in the sense of commonly shared practices. The standards must reflect the complexity of supply relationships between industries, need to curb complexity costs, and are supposed to prepare the ground for clear business cases and thus for rapid scaling of Circular Economy. The white paper at hand collects initial indications that Manufacturing-X as a data ecosystem helps to serve these demands, paving the way for the consideration of standards both on the level of metrics and of data models.

2 Metrics and Indicators

While the overall state of Circular Economy metrics with Key Performance Indicators continues to evolve, it remains fragmented. There are numerous proposals and even standards of metrics and indicators available, complemented by secondary studies in theory and practice. But there is still no single universally accepted standard for measuring circular performance in a way that fully supports strategic decision-making. Most of the available indicators remain mass-based, emphasizing recycling and recycled content. More advanced metrics on product life extension, recovery quality, residual value, and multi-cycle profitability are emerging, but are less standardized and often harder to operationalize.

From a value creation perspective, not all circular loops are equal. For sharing and reflecting insights from the different Manufacturing-X projects, the strength of involving a diversity of viewpoints to ”products“ can be utilized: For instance, in the construction industry products can be made off of individual products or components connected in one system (like raised floors in a building), while other products are supplied as such (like wall colours or floor materials). For the purpose of this study, a distinction is made between integrated products built in systems, products, parts/components and material. Concepts depend strongly on types of industries and roles in value chains. In general, Circular Economy business models capture the highest value by preserving product function for as long as possible. Decisions target R-strategies like reuse, remanufacturing and material recycling, all relevant with regard to the aforementioned product categories – prepared in early decisions in product engineering, but also in use cases like R-grading[1] in product life. Therefore, relevant metrics and indicators can be identified along all these potential decisive situations in product life and life cycles.

Based on literature findings, experiences from involved manufacturing companies and the selected sample cases in projects, the wide variety of metrics can be clustered into four groups:

- Overarching assessment of contributions to Circular Economy business models across life cycle phases and product levels, from economics to disassambly and materials
- Detailed assessment of the costs for later disassembly, assuming that disassembly is a prerequisite for R-strategies like reuse (on part level), repair and remanufacturing
- Detailes assessment of the lifetime by for example extending or prolonging the lifetime of products or materials
- Detailed assessment with focus on end-of life processes, waste management and especially recycling

Applying different approaches on metrics selection or information model design, Manufacturing-X projects indicate demands, but also strong benefits of data ecosystems.

[1] R-grading is the assessment of applicable circular strategies (R-strategies) for a specific product, component, or material instance based on its condition and characteristics at a distinct point in time.

3 Sample Cases in Manufacturing-X

Several projects within Manufacturing-X identified Circular Economy as a promising example to demonstrate the great potential of technologies for data ecosystem. The following paragraphs link to good practices in terms of studies and demonstrators, providing guidance by insightful examples from the variety of industries.

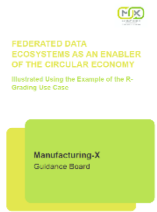
The Construct-X use case “Generation of digital product twins” shows that in the construction sector, product information potentially included in a building resource passport is largely based on Environmental Product Declarations (EPDs), which provide a standardized methodological foundation but show significant variations in quality, granularity, and comparability to other branches. Established standards such as ISO 14025:2010, ISO 14044:2006, EN 15804:2012+A2:2019, ISO 21930:2017, together with evolving regulatory frameworks including the Construction Products Regulation (CPR) and the Ecodesign for Sustainable Products Regulation (ESPR), provide an essential foundation. In this context, sustainability and circular economy criteria are already being incorporated into selected tendering and procurement processes for building supplies such as raised floors, air ducts, and asphalt, in addition to cost considerations. For example, in an ongoing road construction pilot-project, CO_2e emissions are weighted at 30% and price at 70% as part of the bid evaluation process.

The sample product-level case of Sennheiser headsets in the Decide4ECO project focuses on classifing consumer products with regard to European Product Registry for Energy Labelling (EPREL) using MX-based data analysis. This requires, for instance, the representation of disassembly depth. Flexibility with regard to different metrics is tested by implementing the Disassembly Ease Index (DEI) as a prerequisite for assessing the repairability of headphones with regard to integrated assemblies and parts, esp. batteries, and materials. The sample case is implemented in a PLM system environment, including semi-automated data pipelines between manufacturer and suppliers. Metrics are implemented with regard to disassembly depth, handling, costs and tools. The demonstrator was presented at Hannover Messe 2026.

The Fluid 4.0 project focuses on finding suitable circular metric for specific use cases. Within this analysis the project applies Disassembly Indicators in the evaluation of the ease of execution of a particular R-strategy to products and components. The Material Circularity Indicator (MCI) is used as indicator for circular inflow & outflow, that includes not only recycling but also reuse, refurbish, remanufacture. The Average Lifespan Change is included in the study as an indicator in case that a use case supports overall circularity goals. Fluid 4.0 concludes that much of the information needed to determine circular metrics are not yet available either in a way where the calculation can be digitally automated through the Asset Administration Shell (AAS) and data ecosystems or in a traditional way of measuring company’s and product’s performance.

The Chem-X project focuses on material-level circularity with regard to biogenic & renewable, secondary material and waste metrics on all constituents of circular content. The demands and provided solutions cover the combination of recycled content, reused content, biogenic and renewable content, as well as virgin renewable energy derived content and CO_2-based content. Chem-X published its findings, including the "Circularity Guideline for the Chemical Industry: Methodological Framework for Product Circularity Assessment" in https://www.chem-x.de/publication/. The information data model will be published in summer 2026.

With a specific focus on decision making during or at the end of the life of a product, diverse R-grading tools show the great potential of data provision. Data analysis enables extending the life of products or materials. Catena-X, Factory-X, Aerospace-X, Railway-X and Fluid 4.0 show use cases encompassing planned and unplanned maintenance, repair scenarios, and end-of-life situations for components or whole systems. Details are documented in the R-grading whitepaper of the MX Guidance Board.



4 Data and Information Model Demands

While these sample cases and demonstrators clearly indicate great potential of data ecosystems to sustainably implement Circular Economy business models, they also contribute to analysis and design of data and information models. All of the aforementioned sample cases study either single metrics or even the interplay of several metrics, fed by data acquired through the data ecosystem. **Standardization of data models is key to Circular Economy metrics and indicators**: Data and information models refer to standards or at least implement standard meta models like those published for AAS submodels by the Industrial Digital Twin Association (IDTA). Sample cases either incorporate available models like, in case of disassembly indicators, "hierarchical structures", or – when no particular IDTA submodel fulfills all requirements of the described use cases - projects contribute to submodel template initiatives like "Environmental Product Declaration (EPD) Type III" and "End-of-Life", and even initiate new initiatives like on "R-Strategy Decision Support System". The template initiatives are mostly motivated by implementing certain business cases, but through the increase of data availability also enable measuring the Circular Economy activities of companies or impact of products.

Assuming an established data ecosystem backbone and growing standards of metrics-specific information models, use cases show how **digital transformation enables transformation towards material circularity**. Some good practices provided by the family of Manufacturing-X sample cases are:

- development of circular indicator dashboards linked to revenue, margin, and resilience
- measurement of value retention in addition to pure material recovery
- improvement of product and reverse-flow data needed for multi-cycle decision-making
- embedding of circular metrics into product engineering through PLM, service, supply chain, and aftermarket governance

Learning from experiences and driving these learnings further is key for scaling data ecosystems and a circular transformation.

This article demonstrates that Manufacturing-X initiatives took the first steps to advance the possibilities of measuring Circular Economy activities within federated data ecosystems. Yet transitioning from isolated demonstrators to scalable, cross-sector data infrastructure remains the central challenge ahead. Key priorities include establishing a shared cross-sector framework for circular metrics, accelerating IDTA sub-model development for more use cases, and embedding circular metrics directly into existing systems rather than treating them as standalone sustainability tools.