MANUFACTURING-X
GUIDANCE BOARD

FEDERATED DATA ECOSYSTEMS AS AN ENABLER OF THE CIRCULAR ECONOMY

Illustrated Using the Example of the R-Grading Use Case

Manufacturing-X
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Contents

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1 Motivation

As costs continue to rise and market challenges limit growth opportunities, companies face increasing economic pressure to use existing assets more efficiently. High initial invest costs require existing assets to run longer and more reliably. At the same time, dependency on critical raw materials and high material prices make new assets more expensive, so firms turn to digital retrofits and smarter maintenance to keep up value creation capacities without proportionally rising costs. Circular strategies like remanufacturing, repair and reuse of products and materials therefore become a core economic interest, helping to reduce primary raw material demand, stabilize supply and improve cost control by limiting dependencies.

From an ecological perspective, the current economic system which is based on the linear take-make-dispose principle contributes significantly to accelerating climate change and biodiversity loss through intensive resource use, waste production, and significant greenhouse gas emissions (Ellen MacArthur Foundation, 2013; European Commission, 2020).Therefore, the Circular Economy is an alternative concept to today's linear economy that aims to decouple economic growth from the extraction of primary raw materials. This promises a more sustainable economy and more resilient value creation networks.

In practice, the Circular Economy is operationalized through different circular strategies or so-called R-strategies. One well-established and holistic framework in research and practice is the 9R framework by Potting et al. (2017) with the strategies: Refuse (R0), Rethink (R1), and Reduce (R2), which represent the circular principle of narrowing the loop; Strategies R3-R7 represent the principle of slowing-the-loop and are called Reuse (R3), Repair (R4), Refurbish (R5), Remanufacture (R6), and Repurpose (R7); Finally, Recycling (R8) and Recovery (R9) embody the principle of closing material cycles. Despite the promising nature of the Circular Economy concept, its implementation within the industry is currently lagging.

One major challenge in identifying the most promissing R-strategy lies in the availability and accessibility of lifecycle information (Alcayaga & Hansen, 2025; Bühler et al., 2025). Federated Data Ecosystems play a crucial role in solving this problem by enabling standardized data as well as secure and trustworthy information exchange between different value chain partners in a decentralized manner, thereby closing this gap (Otto, 2022). This collaborative approach aims to enhance transparency and fosters the adoption of the most effective circular practices across industries.

This process of identifying the most appropriate R-strategy is commonly referred as “R-Grading”. It serves as a decision-making aid on R-strategies, providing a data-driven logic on whether products should e.g. be maintained, fundamentally refurbished, or replaced based on their state. By leveraging lifecycle data, sensor information, and other metrics, R-Grading enables precise classification into reusability grades, prioritizing higher-value retention strategies to maximize circularity benefits. General decision criteria include economic, ecological, and technical aspects (see Chapter 3).

Given its promising economic and environmental potential, the R-Grading use case is being further developed in various research projects under the KoPa35c, Manufacturing-X, and IPCEI-CIS initiatives with a view to facilitating or accelerating the implementation of a Circular Economy. Within the Circular Economy Topic Group of the Manufacturing-X Guidance Board, the various developments from the projects were analyzed and discussed by the project experts in terms of their similarities and differences in order to enable more informed statements and recommentations on necessary future developments with regard to R-Grading and the business models based on it. The results are presented in this article.

2 Federated Data Ecosystems as enabler of a Circular Economy

As already described under “Motivation”, Federated Data Ecosystems are a promising means of exploiting the potential of a Circular Economy. This chapter first revisits the need for such technology using the R-Grading use case. It then briefly describes the basic characteristics of Federated Data Ecosystems and their contribution to the Circular Economy before examining their application in more detail in Chapter 3 below.

2.1 Challenges in implementing a Circular Economy using the example of the “R-Grading” use case

Within a Circular Economy, products are intended to remain in use for extended periods and to be utilized more intensively. To be able to do this, it is important to make the right decision, when a failure occurs, a service is planned or one use phase ends. Several critical challenges hinder effective decision-making and operational efficiency in these situations:

- **Insufficient use-phase information and lack of product knowledge**: Due to a lack of product knowledge by relevant actors and increasing technical complexity, informed decisions on end-of-life treatment are often impossible. Particularly missing data from the product and component usage phase poses significant obstacles to informed decision-making related to R-strategies and maintenance.
- **Digitalized expert knowledge for product diagnostics**: The diagnostics of defects and product condition depend on the detection of both visible and non-visible conditions, which is often done based on tacit knowledge of individual, experienced service structures. Machine-readable decision guidelines for condition evaluation are frequently missing.
- **Inefficient processes**: Manual information flows (e.g. e-mails, telephone), complex logistics and time-consuming manual disassembly and assessment procedures are causing inefficiencies. While in-house processes can be streamlined with corporate IT-systems, breaks in media chains are still prevalent in inter-organizational communication.
- **Interoperability**: Numerous players with different requirements, standards, and communication interfaces are involved throughout the entire product life cycle. This leads to fragmented data landscapes and makes consistent information exchange difficult. These differences complicate data usage across different actors and prevent the scalability of Circular Economy solutions.
- **End-of-life treatment is often not sufficiently considered at the beginning of the product life cycle**: Possible R-strategies and decisions regarding their applicability are not considered during the development phase, which later has a negative impact on maintenance, repair, refurbishment, and recycling. End-of-life aspects, considered in the design phase, could provide suitable guidelines and improved service opportunities for products in the field.

To address the outlined challenges, the use case R-Grading proposes a decision support system that leverages technical product and lifecycle data to enhance decision-making regarding R-strategies. This system integrates various data sources, including for example material and product information, operational data from use phase, as well as economic and ecological background information, which can include dynamic and static data points. The decision is therefore based on the respective product and its use. This increases the efficiency of the decision-making process, enables well-informed decisions, and opens up new opportunities for profitable circular business models for a wide range of stakeholders within the ecosystem.

The data sources are diverse, since part of the data needs to be supplied by the manufacturer of the component (e.g. list of spare parts) and other data points need to be provided by the user of the component (e.g. machine hours). To be able to exchange the data and to enable the R-Grading through a decision support system, a functional data exchange system across multiple stakeholders is needed. One way to achieve this in a secure and trustworthy manner is through Federated Data Ecosystems, which promote decentralized data exchange. The next section describes how this approach works and what requirements a Circular Economy imposes on such a data ecosystem.

2.2 Federated Data Ecosystems as the solution

In today's production and supply chains, data exchange is characterised by rigid, bilateral connections based on established technologies, such as Electronic Data Interchange (EDI), between partners. However, digital platforms have enabled companies to manage data within their organisations and, in some cases, request data from partners and suppliers. These solutions tend to be proprietary and managed centrally by a single player, which limits flexible, multilateral data exchange in complex value creation networks for several reasons. Consequently, cross-company Federated Data Ecosystems are currently emerging, enabling various use cases such as the Circular Economy. The goal is to enable seamless, secure, and sovereign cross-company data exchange. Such ecosystems are either under development or already in use in industries such as mobility (Mobility Dataspace) and automotive (Catena-X). The following section briefly describes how Federated Data Ecosystems are characterized (Otto et al., 2019):

- **Data and Technology Sovereignty**: Guarantees that each participant retains full authority over their data at all times. Legally binding and clearly defined usage agreements enable participants to set specific terms regarding who can access their data, under what circumstances, and for which purposes.
- **Interoperability**: Supports seamless, digitally-enabled collaboration between organizations across technical, syntactic, semantic, organizational, and regulatory layers. This applies both to interactions within a single data space and across multiple data spaces. With frameworks like the Asset Administration Shell (AAS), it ensure seamless integration between diverse digital systems.
- **Trust-by-Design**: Established through the integration of trust anchors in the technological backbone. Built-in security protocols and standards ensure that data-sharing happens within a trusted network, minimizing risks. For example, the use of verified, legally binding, and tamper-resistant identities enables transparent and reliable identification of all data providers and consumers.

Federated Data Ecosystems are configurable and modular frameworks that ensure interoperable and scaleable data exchange across different industries and use cases. To participate, companies need specific technical data exchange stacks. These stacks consist of various components, e.g. the Eclipse Dataspace Components (EDC), which are developed and refined as open source and are an important part of Catena-X. The core component is the Asset Administration Shell (AAS), which enables the integration and standardization of data. It is also being implemented in Catena-X, Factory-X, Fluid 4.0, Railway-X and Aerospace-X. These research projects also further developed the overall technical data exchange stack. One resulting open approach hailing from Factory-X and containing different components depending on the use case is the so-called MX-Port concept. MX-Port configurations contain EDC, OPC-UA and AAS elements. They use international industrial standards for manufacturing and data exchange, which they have further developed. The aim is seamless interoperability of the Manufacturing-X data ecosystems. However, this article does not focus on the technical details, but rather on the implementation of the R-Grading use case.

In a nutshell, Federated Data Ecosystem provide companies with a common decentralized digital infrastructure designed to enable seamless, secure and sovereign data-sharing across industries. Unlike centralized cloud-based storage systems, Federated Data Ecosystems provide a trusted, distributed environment where each participant retains ownership and control over how their data is accessed and used. The decentralized approach not only gives participants greater autonomy but also fosters collaboration by creating a level playing field.

This is essential for addressing modern challenges that require cross-industry collaboration, including sustainability, supply chain transparency, and industrial efficiency. This applies in particular to the R-Grading use case described above. Its implementation in various industries, with a focus on similarities, differences, and characteristics, is described below.

3 R-Grading enabled by Federated Data Ecosystems within different industries

R-Grading is seen as a crucial starting point for efficient Circular Economy processes across industries. Using Federated Data Ecosystems enables information exchange and stronger collaboration between value chain actors, which as a result allows for the execution of an efficient R-Grading process. This chapter gives an overview of implementation approaches of R-Grading systems in different industries (Automotive, Aviation, Railway, Machine and Plant Engineering, and Fluid Power) based on various criteria:

- The **application area** is determined by the R-strategies, which are central to the selection process using the R-Grading tool.
- The **actors** are specified and allocated to a life cycle phase, since e.g. service providers can take on several functions and tasks. An actor can act in a role as a user of the tool, as a data provider and/or as an infrastructure provider.
- The **decision criteria** describe the criteria used by the R-Grading tool to decide on an R-strategy. It is clustered into technical feasibility, profitability and environmental criteria and examples are given.
- The **data** provided to the tool for analysis is clustered into technical, economic, environmental, operational and assessment data, and examples from the specific projects are given. Furthermore, it is specified if data models are standardized according to IDTA submodels, Catena Semantic Aspect Models (SAMM) and/or proprietary solutions.
- The **technology** describes the infrastructure used for data exchange in a Federated Data Ecosystem. A distinction is made between AAS, EDC, MX-Port variants, and proprietary solutions based on standards.
- The **tool development stage** classifies how far the tool has already been developed in the various projects. For classification the Technology Readiness Level (TLR) according to ISO 16290 is used.

3.1 Automotive (Catena-X)

The R-Grading tool of Catena-X focuses on the EoL-vehicle dismantling decision process. It enables faster, data-driven decision-making of decomissioned end-of-life-vehicles and while assisting the dismantling, it leads to the most suitable R-strategy for automotive components. The project has resulted in initial data models, a conceptual decision-making logic and demonstrator mock-up.

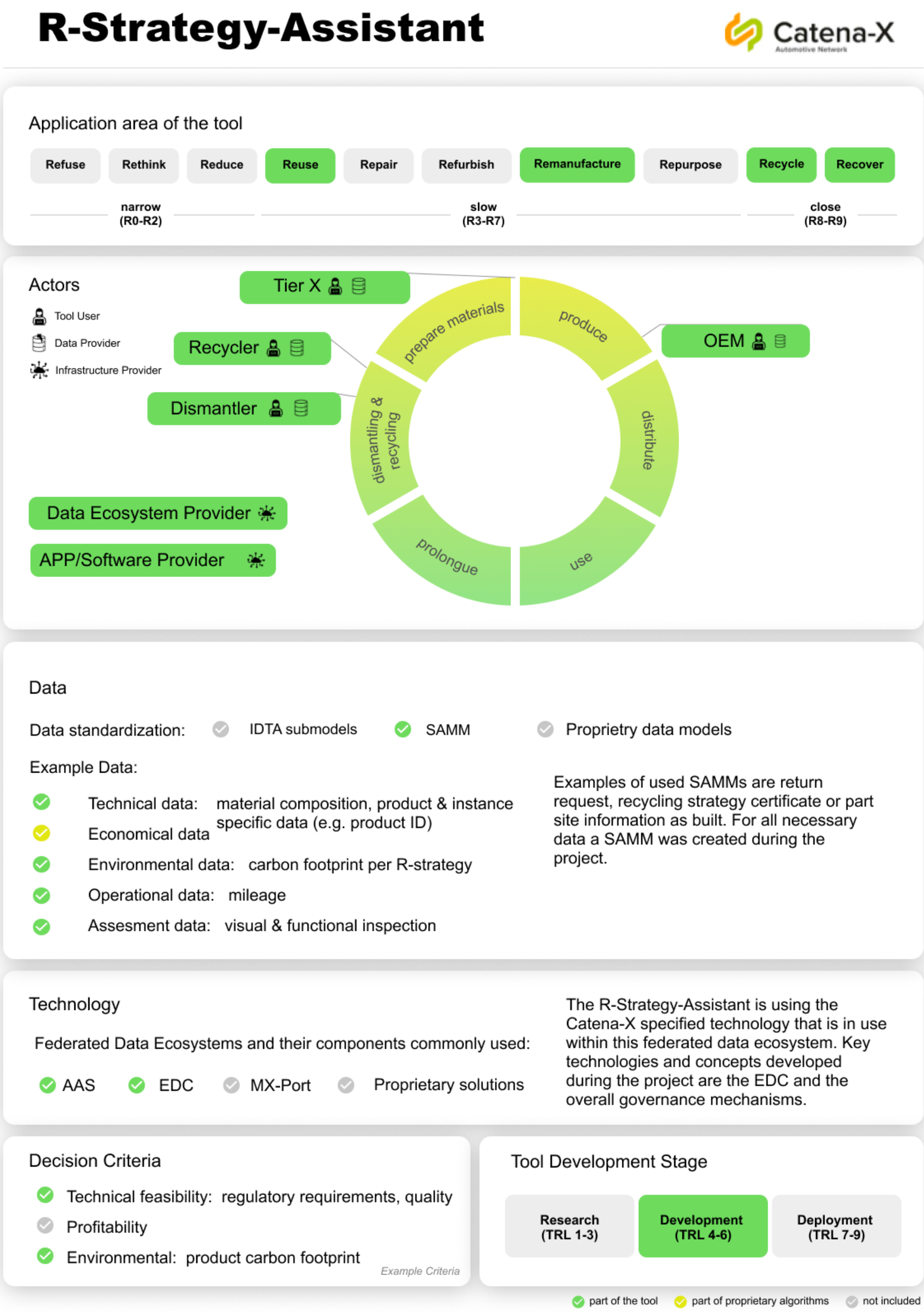

Figure 1: R-Grading use case in Catena-X

3.2 Aviation industry (Aerospace-X)

R-Grading in Aerospace-X supports end-of-life as well as maintenance decisions regarding the selection of the most suitable R-strategy for aviation components. The project will lead to initial data models and conceptual decision-making logic for exemplary components.

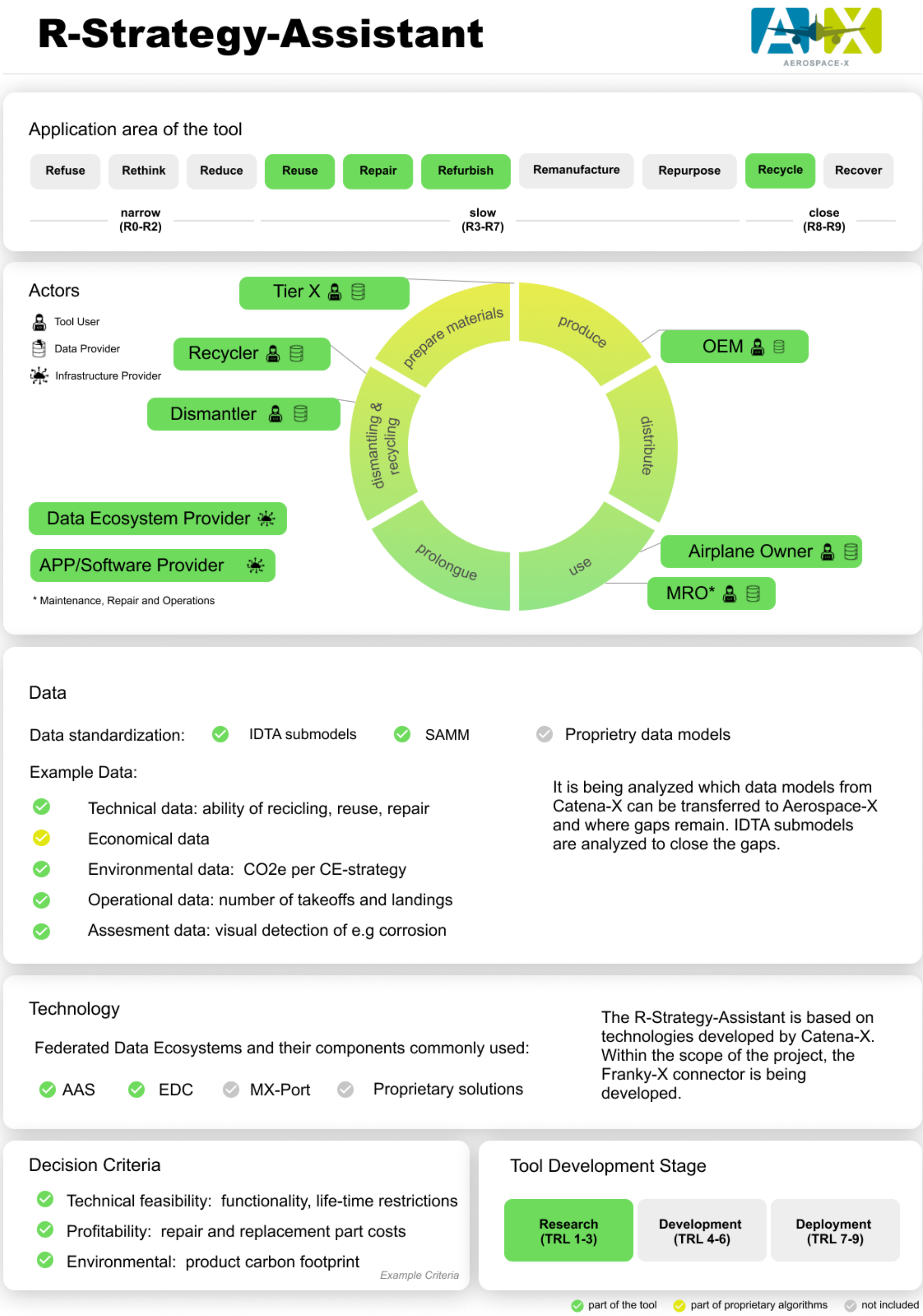

Figure 2: R-Grading use case in Aerospace-X

3.3 Railway industry (Railway-X)

The R-Grading tool of Railway-X focuses on an AI-based decision support for the end-of-life management, maintenance and repair work. During the operational work within the product's service life and at the end of a product's lifecycle, the most suitable R-strategy will be suggested by using knowledge and data. This will be tested on exemplary rail components.

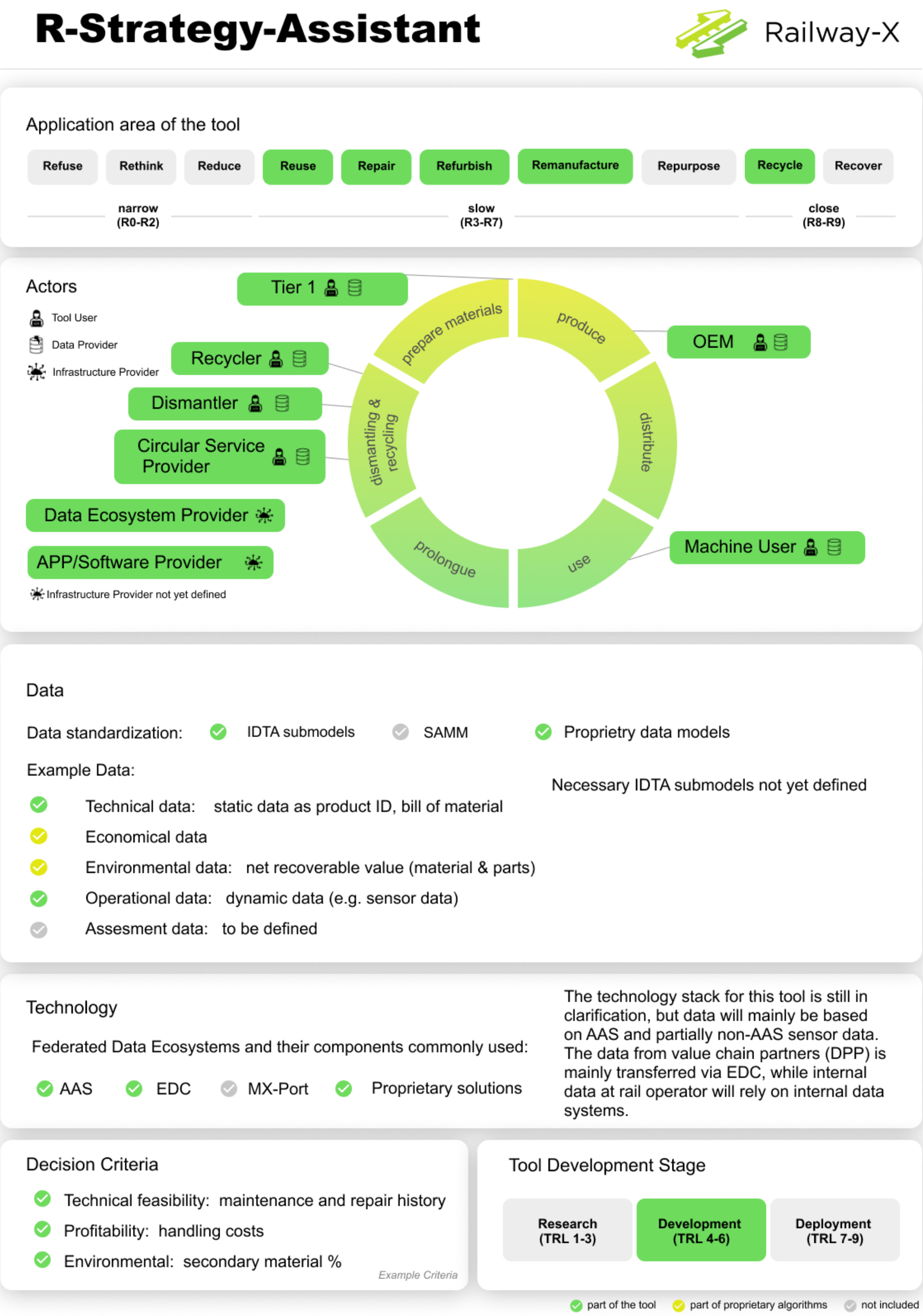

Figure 3: R-Grading use case in Railway-X

3.4 Machine and plant engineering (Factory-X)

Factory-X focuses on creating a unified infrastructure for the exchange of R-Grading-related operational data between machine builder, factory operators, and other relevant actors during the machine's use phase or at end of its life. The specific R-Grading algorithm itself is not part of the solution, but is proprietary of the respective component manufacturers. The results will be shared back with the factory operator via the R-Grading tool.

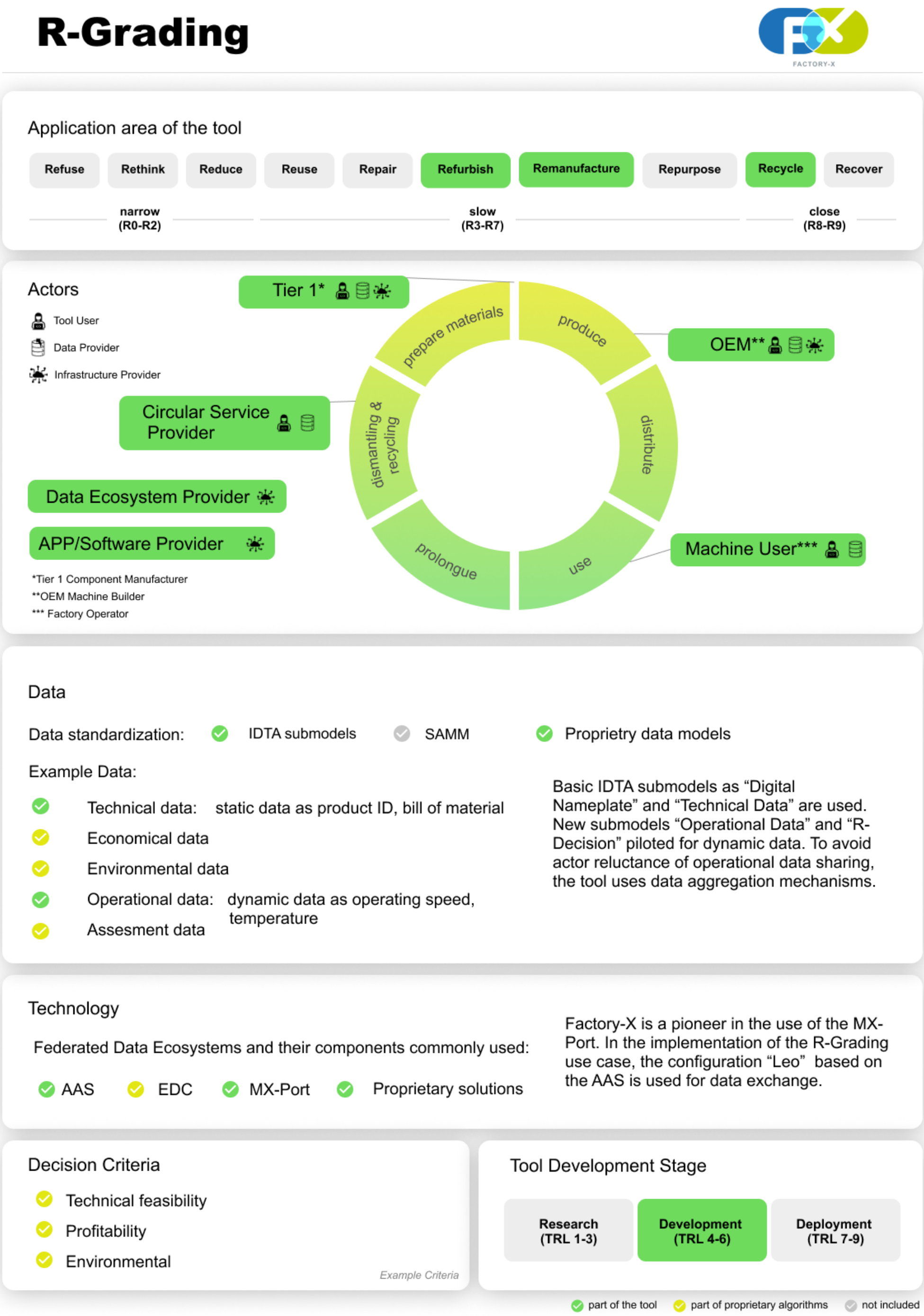

Figure 4: R-Grading use case in Factory-X

3.5 Fluid power industry (Fluid 4.0)

R-Grading in Fluid 4.0 illustrates the process and decision logic for selecting the best R-strategy for hydraulic or pneumatic products during and after their use. A data model has been developed that serves as the basis for providing information about the product, intensity of use, and possible R-strategies. This approach serves as a blueprint for instantiating product-specific R-strategy processes and logics.

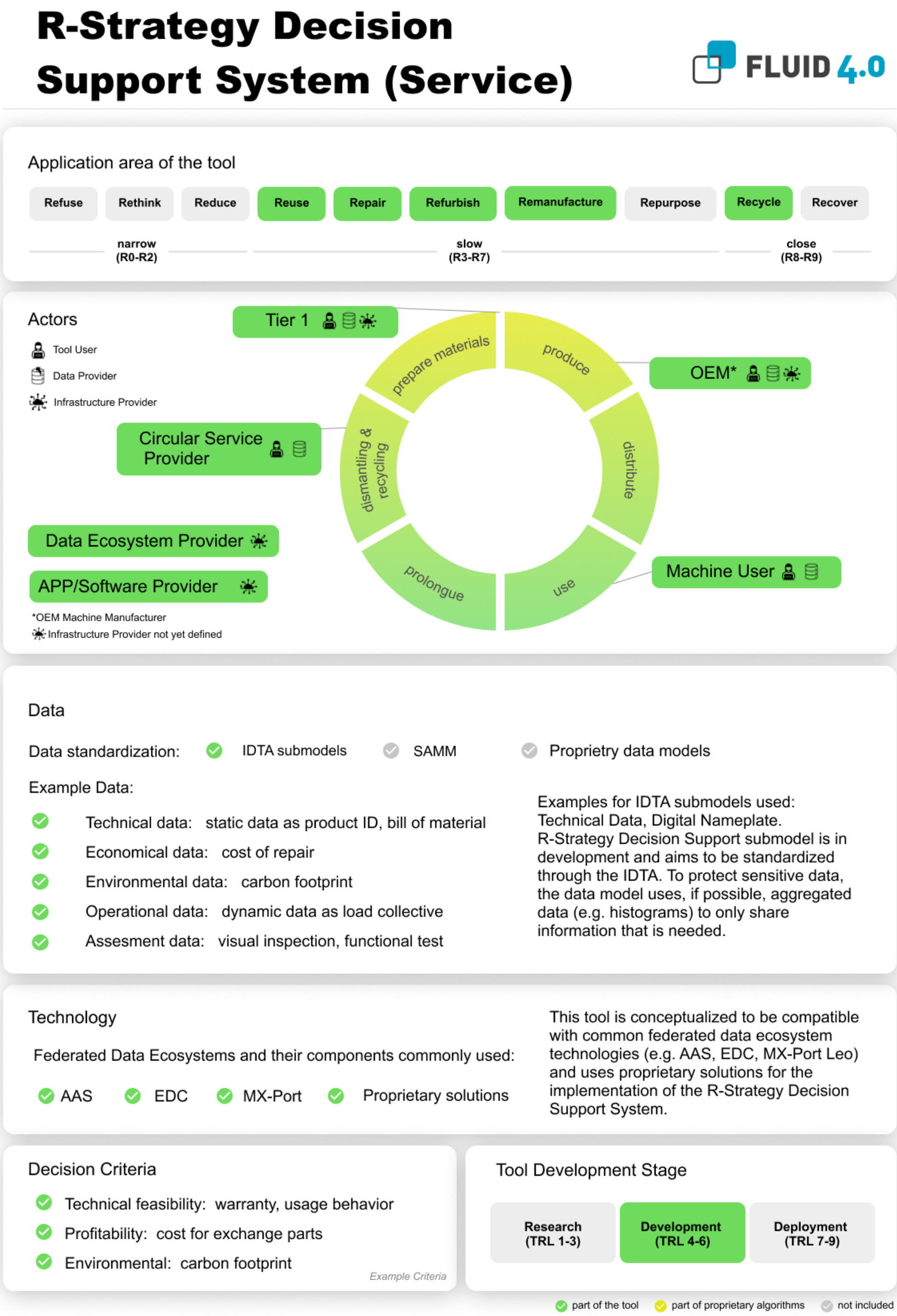

Figure 5: R-Grading use case in Fluid 4.0

3.6 Comparison of different industries

The R-Grading tools described in this article are designed to select the most suitable R-strategy. However, projects from different industries derived their concepts with altering focus areas, methodologies, and overall research scopes to achieve this objective. This subchapter analyzes and compares the differences and commonalities among the taken approaches. It is important to note that all R-Grading tools are still in the conceptualization stage, as they are being developed within publicly funded research projects. As a result, while the concepts can be compared, practical application cannot yet be evaluated due to a lack of empirical data.

The use cases for R-Grading tools are diverse, encompassing planned and unplanned maintenance, repair scenarios, and end-of-life situations for components or whole systems. Accordingly, the R-strategies that form the **application area** of the tools also differ (see Figure 6). Pre-use strategies (refuse, rethink, reduce) are not considered in any of the tools from the different industries, as all of them focus on the use and post-use phases of an asset. The strategies reuse, repair, refurbish, remanufacture, recycle, and recover are within the scope of at least one tool. In contrast, repurpose is not a focal point, possibly due to industry-specific contexts or the current lack of application of this R-strategy within these sectors. Looking at the industries, in Catena-X the tool finds application for end-of-life vehicles and therefore emphasizes R-strategies at that stage (reuse, remanufacture, recycle, recover). Whereas the other discussed research projects focus more on R-strategies during the product life-cycle rather than on closing-the-loop strategies: Factory-X (refurbish, remanufacture, recycle), Fluid 4.0 (reuse, repair, refurbish, remanufacture, recycle), Aerospace-X (reuse, repair, refurbish, recycle), and Railway-X (reuse, repair, refurbish, remanufacture, recycle). Therefore, these projects consider the products' use phase. For this reason, recycling is a possible strategy of the R-Grading process in these projects but is not the focus.

Figure 6: Comparison of relevant R-strategies in the R-Grading use case of different industries

The chosen R-strategies do not correlate with specific tool characteristics, suggesting that each tool is tailored for its industry but can be adapted for other scenarios as needed during implementation. Nevertheless, application scenarios in some industries are restricted by regulatory requirements (e.g., in the aerospace industry in particular, but also in the automotive industry, some R-strategies are completely ruled out for safety-related components).

Another key aspect is the consideration of the **actors** involved and their interactions (roles). Three primary roles are identified: data provider, infrastructure provider, and tool user. These roles may be fulfilled by one or multiple actors, and a single actor may assume more than one role. Specialized actors such as the Data Ecosystem and Software Provider typically supply the infrastructure for information exchange, thereby enabling the system component of the R-Grading tool. All other actors along the value chain, with the exception of these two actors, can assume the role of tool users or data suppliers, depending on the situation. Data providers are divided into two categories: those supplying product development data or information on the correlation between health status and possible R-strategies (primarily static data from manufacturers), and those providing data from the use phase and life cycle extension (dynamic data originating from asset users or circular service providers). Only in Factory-X and Fluid 4.0 do actors from the value chain also act as infrastructure providers for R-Grading. Nevertheless, the roles and responsibilities do not differ significantly across projects or industries (see Figure 7).

Figure 7: Comparison of actors and roles in the R-Grading use case of different industries

There is a consensus that technical feasibility is the most critical **decision criteria** for selecting the appropriate R-strategy, followed by profitability, which encompasses material and process costs as well as component availability. Although environmental considerations are not deemed highly influential, relevant information, such as the product carbon footprint, is included in the decision-making process. Notably, only the Factory-X R-Grading tool has not established generic decision criteria, since the development of decision logic is the responsibility and intellectual property of the respective component manufacturers. It does not fall within the scope of the R-Grading tool, which only covers the infrastructure for automatic data exchange.

All R-Grading systems developed in the five projects rely on the exchange of standardized **data**. The level of detail in which the data has been described varies according to the scope of the tool, and even within industry-specific projects, the required data is highly dependent on the individual product. Standardized data modeling also differs, with IDTA submodels and Catena semantic aspect meta models (SAMM) being used. Due to the wide variety of products, proprietary models are also employed. These data models include data points that are shared between actors and other more sensitive data points that are only used within one organization to determine the most suitable R-strategy. To address actors' hesitancy of sharing operational data, Factory-X and Fluid 4.0 rely on data aggregation mechanisms tailored to the specific needs for the R-Grading algorithms. However, a general data structure can be outlined as follows:

- **Static technical data**: BOM, ID, expected lifetime, possible R-strategies.
- **Economic data**: Disassembly times, costs associated with the execution of R-strategies, delivery time, costs of alternatives.
- **Environmental data**: Environmental footprint.
- **Dynamic operational data**: Usage data e.g. operating hours, operating conditions, sensor data, negative events (R-Grading often requires only aggregated data, such as histograms).
- **Assessment data**: Visual inspection, functional status/tests.

As described in previous chapters, the R-Grading tools are executed through Federated Data Ecosystems. The underlying **technology** concepts differ in how the actors within the Federated Data Ecosystems exchange information. The projects use different components for this purpose, in particular the EDC and MX-Port components, but also proprietary solutions developed using open source standards. All projects use the AAS to provide data.

All R-Grading tools use the AAS to provide data but differ regarding the components for data exchange.

When considering the **development phase**, all tools are below TRL 7 and are therefore either still in the research stage or in design or development phase.

In general each project puts its focus on specific parts of the R-Grading use case. Catena-X builds the foundation as it was the first project that developed the R-Grading use case. Aerospace-X builds on these developments from Catena-X and further evolves and adapts it to the new industry. Factory-X puts a strong focus on the infrastructure development for operational data exchange and the R-Grading business processes. Fluid 4.0 focuses on the needed data, business process development and interaction between actors. Railway-X considers the development of the decision algorithms as its main task. All projects together describe a very holistic tool that aims in the same direction, is partially compatible, but still needs development to adjust and standardize it, to be broadly applied.

4 Recommendations for enabling a Circular Economy with Federated Data Ecosystems

Analyses of various industries show that, despite its promising potential for promoting Circular Economy practices, the application of R-Grading is still in its infancy. This also reflects the state of Circular Economy practices in general in the industries considered in this article. Therefore, this chapter describes targeted measures designed to accelerate the implementation and operationalization of use cases such as R-Gading to facilitate the transition to a Circular Economy enabled by Federated Data Ecosystems. The recommendations relate to different levels of action. Every stakeholder can influence specific levels, which is why the recommendations have been structured into product manufacturers, digital service providers, cross-company collaboration and legislators as to direct readers to the right recommendations.

4.1 Recommendations for product manufacturers

R-Grading readiness in product development and business models:

During the product development phase, R-strategies are often not systematically integrated. This gap can be attributed to limited knowledge of circular principles as well as the persistence of traditional business models. These conventional models—and the mindsets that accompany them—tend to prioritize revenue from the sale of new products rather than from service-oriented or circular offerings. Moreover, products often lack embedded intelligence required to generate and transmit relevant data, impeding the assessment of their suitability for various R-strategies. To enable more sustainable and long-lasting products, the criteria used for R-Grading (such as repairability, reusability, or refurbishability) must be further developed and strengthened. Therefore, companies should consider and specify prolong and end-of-life strategies when designing future products as well as define data requirements for these strategies. Clearer definitions, measurable indicators, and standardized assessment methods are essential to ensure that product life-extension becomes an integral part of design decision-making.

From pilot projects to scaling effects and economic viability:

Especially small and medium-sized enterprises (SMEs) frequently face additional hurdles, including a lack of expertise in digital solutions and insufficient resources to finance the implementation of use cases like R-Grading. There is still a risk associated with investing in use cases, which have yet to be fully implemented or tested in real-world projects. It is therefore particularly important that companies with investment capacity carry out further pilot projects to demonstrate scalability opportunities and the economic viability of circularity applications.

4.2 Recommendations for digital service providers

Simplified R-Grading Apps for user accessibility:

Complex standards and systems on the Federated Data Ecosystem level make operation of R-Grading prototype tools only viable for experts. To become a success, these tools and Federated Data Ecosystems in general require simple usage, which are also accessible for non-technical experts with a simple push of a button. Further efforts are necessary to simplify tool adoption and usage to allow for broad scaling especially across SMEs with less resources.

Formalization of expert knowledge for Circular Economy with appropriate AI-methods:

Many circular processes rely on tacit experiential knowledge rather than formalized data, particularly in service (e.g. repair or maintenance) where expertise resides in skilled workers' minds. Robust R-Grading algorithms thus require not only product-specific digital data but also appropriate algorithms or AI-methods to capture, formalize, and integrate this domain expert knowledge. Only this combination enables expert-level AI decision support systems for R-strategies.

4.3 Recommendations for cross-company collaboration

Trust structures to overcome reluctance to share data:

At the organizational level, there is often reluctance to share data along the value chain due to concerns about intellectual property protection and the confidentiality of competitive data. This is particularly true for Circular Economy business models that require sensitive business, product, and operational data across the entire value chain. This emphasizes the importance of further elaborating on trust structures within Federated Data Ecosystems, as they aim to build trust between actors, regulate access to sensitive information and share these only selectively, and establish mechanisms for validating data reliability.

Initiatives for adoption of existing standards:

Interoperability challenges remain at the forefront, particularly among various systems and standards such as MX-Port, EDC, and semantics as IDTA submodels and SAMM. The lack of adoption of standardized interfaces complicates seamless data exchange. Furthermore, the limited availability and varying quality of data restricts the effectiveness of R-Grading tools. Although all projects strive for uniformity and standards within their respective industries, further initiatives such as the Manufacturing-X Guidance Board with its topic groups are necessary to achieve greater harmonization.

Development of joint R-Grading tool kit:

Based on the individual priorities of each R-Grading tool within the described projects, it is a unique opportunity to unify and join those developments to build a generic cross-industry tool kit. This tool kit could combines the different building blocks of the individual projects into one concept with basic tools that allow all companies to implement stadardized R-Grading with a minimum of effort in their value chain.

4.4 Recommendations for legislators

Financial support for the basic digitization of SMEs:

Changing and adding new value creation processes also presents challenges, as many industries have low digital maturity and little to no digital literacy to implement R-Grading solutions. For instance, automotive repair shops and recyclers typically do not engage in systematic digital communication with OEMs, limiting the flow of information necessary for effective R-strategy selection. For this reason, it is necessary that SMEs in particular continue to receive support for the basic digitization of processes so that circularity use cases can be implemented across the board in the future.

Create further (financial) incentives for Circular Economy practices:

In recent years, regulatory innovations (e.g., ESPR-DPP, CSRD) have created numerous frameworks for a more digital Circular Economy. Nevertheless, the system remains stuck in a linear economy, which is why even digitally enabled Circular Economy practices often remain below the economically viable threshold. For this reason, further incentives, particularly of a financial nature, are needed to encourage companies to shift their economic practices from linear to circular.

Simplified legal guidelines for data sharing:

Within a Circular Economy data sharing among all relevant actors is essential but doing this even within Federated Data Ecosystems is complex, particularly due to the diverse regulatory frameworks governing data exchange (e.g., GDPR, Data Act). These regulatory uncertainties can slow down the adoption of R-Grading tools and create additional compliance burdens for organizations. For this reason, it is necessary to harmonize standards and regulations and to tailor them to the feasibility for all companies.

5 Conclusion

The article "Federated Data Ecosystems as an enabler of the Circular Economy" highlights the transformative role of Federated Data Ecosystems in supporting the implementation of a Circular Economy, particularly through the use case of “R-Grading”. Given the challenges companies face in transitioning from linear to circular business models, R-Grading offers data-driven decision support to identify the optimal R-strategies for products, components and materials.

By integrating lifecycle data and promoting secure and decentralized data exchange between different actors in the value chain, Federated Data Ecosystems create the necessary transparency and interoperability. These systems enable companies to develop more efficient R-strategies executions, which bring both environmental and economic benefits.

The article shows that the implementation of R-Grading in various industries - such as automotive, aviation, railway, machine and fluid power - is promising but still in its infancy. Recommendations for promoting the Circular Economy and Federated Data Ecosystems, aimed at product manufacturers, digital service providers, cross-company collaborations, and legislators, underscore the need for a coordinated approach to overcome existing hurdles.

Overall, it is clear that the combination of technological innovations and a structured, trust-based exchange of data is crucial to fully exploit the potential of the Circular Economy and thus enable a more sustainable future. By creating new service offerings and increasing service revenues, companies can diversify their business models and reduce their dependency on selling new products. Keeping materials in circulation not only improves resource availability and decreases material costs but also strengthens the resilience of supply chains, making organizations less vulnerable to disruptions. Ultimately, the collaborative use of R-Grading tools fosters more robust, sustainable, and adaptable value chains, benefiting both individual enterprises and the broader economy.

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