DACE

Datenkompetenzzentrum für Circular Economy Daten

GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

Finanziert von der Europäischen Union NextGenerationEU

Verfasser:

Kommentiert [ma1]: Shall we switch to English straight away? I mean, throughout the document, apart from the German summary

M3.1.1 Dataspace

Part 1: Theory & Intro

Dissemination Level	PU (Public)
Abgabedatum	
Version	1.0.0
	Verantwortung: Ali Nazeri (DFKI)
Autoren	Mitarbeit:

- Ali Nazeri (DFKI)
- Abdullah, Farrukh (DFKI)

Zusammenfassung

Kommentiert [AF2]: Write this chapter (max.⅓ page). Do also a german version

Kommentiert [AN3R2]: done

Strategien der Kreislaufwirtschaft (Circular Economy, CE) sind zunehmend auf den Austausch zuverlässiger Lebenszyklusdaten über Organisationsgrenzen hinweg angewiesen. Gleichzeitig sind CE-bezogene Informationen häufig auf heterogene Systeme verteilt, während Anforderungen hinsichtlich Interoperabilität, Vertraulichkeit und Datensouveränität die organisationsübergreifende Zusammenarbeit erschweren. Datenräume (Dataspaces) stellen einen vielversprechenden Ansatz für einen kontrollierten und dezentralen Datenaustausch in solchen Umgebungen dar. Dieser Bericht untersucht die Rolle von Datenräumen im Kontext der Kreislaufwirtschaft und analysiert relevante Technologien und Architekturen, darunter Solid, IDS-basierte Ansätze, Gaia-X, Eclipse Dataspace Connector, FIWARE und Ocean Protocol. Darüber hinaus werden zentrale Anforderungen der CE betrachtet, beispielsweise Lebenszyklus-Traceability, semantische Interoperabilität, selektiver Datenaustausch sowie die Unterstützung von Digitalen Produkt Pässen. Auf Basis dieser Analyse dokumentiert der Bericht den im DACE-Projekt gewählten Ansatz, bei dem ein Solid-basierter Datenraum als Grundlage für den Austausch CE-relevanter Daten ausgewählt wurde. Die Entscheidung für Solid basiert insbesondere auf der dezentralen Web-Architektur, der Unterstützung von Linked-Data-Technologien, der Flexibilität sowie der Eignung für Forschungs- und Prototyping-Umgebungen. Zusätzlich werden aktuelle Einschränkungen des gewählten Ansatzes, insbesondere hinsichtlich Governance und Usage Control, diskutiert.

English Version

Circular economy (CE) strategies increasingly depend on the exchange of reliable lifecycle data across organizational boundaries. However, CE-related information is often fragmented across heterogeneous systems, while concerns regarding interoperability, confidentiality, and data sovereignty complicate cross-organizational collaboration. Dataspaces have emerged as a promising approach for enabling controlled and decentralized data exchange in such environments. This report examines the role of dataspaces in CE and analyzes relevant technologies and architectures, including Solid, IDS-based approaches, Gaia-X, Eclipse Dataspace Connector, FIWARE, and Ocean Protocol. In addition, the report discusses key CE requirements such as lifecycle traceability, semantic interoperability, selective data sharing, and support for Digital Product Passports. Based on this analysis, the report documents the approach selected within the DACE project, where a Solid-based dataspace was chosen as the foundation for CE-related data exchange. The selection was motivated by Solid's decentralized Web-based architecture, support for Linked Data technologies, flexibility, and suitability for research and prototyping environments. The report also discusses current limitations of the selected approach, particularly regarding governance and usage control.

Table of Content

List of Figures and Tables

1 Introduction

The circular economy represents a shift from the traditional linear model of production and consumption toward a more resource-efficient approach to value creation. Instead of following the logic of "take, make, dispose", CE aims to keep products, components, and materials in use for as long as possible [1], [9]. Achieving this objective requires reliable information about products, materials, supply chains, and lifecycle processes. Without trustworthy and accessible lifecycle data, circular strategies cannot be operationalized; for example, a recycler cannot assess material recoverability without composition data, or a repairer cannot act without maintenance history, and a Digital Product Passport (DPP) cannot be populated without verifiable origin and process information.

In practice, such information is often fragmented across different organizations and systems. Relevant data may be stored by manufacturers, suppliers, service providers, recyclers, or public authorities. As a result, circular strategies such as reuse, repair, remanufacturing, recycling, and Digital Product Passports depend on the ability to exchange data across organizational boundaries [3], [5]. At the same time, this exchange must respect data ownership, confidentiality, and regulatory requirements. Recent studies show that missing or inaccessible lifecycle data remains a major obstacle for CE implementation. Serna-Guerrero et al. demonstrate that incomplete and fragmented data limit efficient material recovery and recycling processes in industrial ecosystems [2]. Similar observations are reported in studies on CE governance and interoperability, in which the lack of shared digital infrastructure complicates collaboration among stakeholders [6]. Therefore, the need for cross-organizational data exchange arises directly from the fact that the data required for circular decisions is generated by one actor but consumed by another, which is precisely the gap that a CE Dataspace is intended to complete.

Dataspaces address this challenge by enabling controlled data sharing between independent actors. Unlike centralized platforms, dataspaces provide a federated environment in which participants can exchange data while maintaining control over access and usage conditions [3], [4]. In the CE context, this is especially relevant because lifecycle data is often sensitive, distributed, and required by multiple stakeholders at different stages of the product lifecycle. Within the DACE project, a Solid-based dataspace is developed and deployed to support the exchange of CE-related data. Solid is selected because it already provides a decentralized, Web-based infrastructure for storing and sharing data via personal or organizational data stores [7]. Its support for Linked Data technologies, Web identities, and fine-grained access control makes it suitable for practical CE data-sharing scenarios [7], [11]. At the same time, the deployment must be considered in relation to the requirements and limitations of CE data sharing, especially regarding governance, findability, interoperability, and usage control.

1.1 Scope of the Report

The objective of this report is to document the conceptual background, technology selection, and deployment of a Solid-based dataspace for circular economy data within the DACE project. The report does not propose a new dataspace architecture. Instead, it examines existing dataspace concepts and components and explains why Solid was selected as a suitable solution for the project requirements and constraints. The report first introduces the main principles of dataspaces and

Kommentiert [AF4]: Citation are mismatched. Please make sure the references are correct and match the text. Also the numbering is faulty. There are numbers which I did not find in the references list

Kommentiert [AN5R4]: done

Kommentiert [AF6]: In general, make sure to use the same terminology e.g. dataspace or data space etc.

Go through it again and streamline it

Kommentiert [AN7R6]: done

Kommentiert [ma8]: There is no explanation here as to why this is needed now. At present, it simply states that it is needed, but not why. This explanation is important at this point and should be well-founded, as it forms the basis for a CE Data Space.

Kommentiert [AN9R8]: Added: an explanation of why reliable cross-organizational lifecycle data is needed. This is the basis for a CE Data Space.

Kommentiert [ap10]: Usually, I prefer Dataspace instead of "Data Space", but for the document, I'm fine with this variant ;)

Kommentiert [AN11R10]: Done!

Kommentiert [ma12]: This section also provides some indication of the chapters that follow. However, the chapters are only described implicitly.

Could we please make the structure of the document clearer here?

For example: 'First, the basic elements of a Data Space are defined (see Chapter 2). Then...'

Kommentiert [AN13R12]: The scope of the report has been added.

discusses relevant technologies such as Solid, IDS-based architectures, Gaia-X, Eclipse Dataspace Connector, FIWARE, and Ocean Protocol. It then analyzes the requirements of CE data sharing, including lifecycle traceability, semantic interoperability, selective data access, and support for Digital Product Passports [4], [5], [6]. Based on this analysis, the report describes the design decisions, deployment structure, services, and configurations used in the DACE Solid-based dataspace. The report is structured as follows. First, the basic elements and core components of a dataspace are defined (Chapter 2). Then, relevant dataspace technologies and architectures are described in general terms (Chapter 3). Building on this, the specific requirements and challenges of CE data sharing are analyzed (Chapter 4). Finally, the selected DACE approach is presented and justified by evaluating the available technologies against these CE requirements (Chapter 5).

Kommentiert [ma14]: To someone not familiar with Data Space, this might read as though these are identical technologies that are interchangeable. In reality, however, these are technologies designed for different purposes or areas of application. Could we perhaps highlight this point here?

Kommentiert [AN15R14]: In chapter 3.3 an explanation has been added.

2 Fundamentals of Dataspaces

2.1 Concept and Core Components

Dataspaces are decentralized infrastructures that enable controlled data exchange between independent participants [3], [8]. Unlike centralized platforms, dataspaces do not require all data to be stored in a single repository. Instead, data remains under the control of the respective provider while being made accessible through shared standards, interfaces, and governance rules [4], [8]. This approach supports interoperability across organizational boundaries while preserving data sovereignty and reducing dependency on central platform operators.

A key objective of dataspaces is to establish trusted environments for data exchange. To achieve this, dataspaces combine technical and organizational mechanisms for identity management, access control, semantic interoperability, and policy enforcement [8]. Although implementations differ depending on the selected architecture, most dataspace approaches are based on a set of common components [8].

The core components of a dataspace as presented in Figure 1, typically include [8]:

- **Connectors** for data exchange and communication
- **Identity providers** for authentication and participant verification
- **Metadata catalogs** for registering and discovering data assets
- **Policy and access-control mechanisms** for managing permissions and usage conditions

Connectors act as the interface between participants and enable secure communication between systems. *Identity services* ensure that only verified entities can access resources within the dataspace. *Metadata catalogs* provide descriptions of available datasets and services, which improves discoverability and interoperability. *Policy mechanisms* define how data can be accessed and under which conditions it may be used [8].

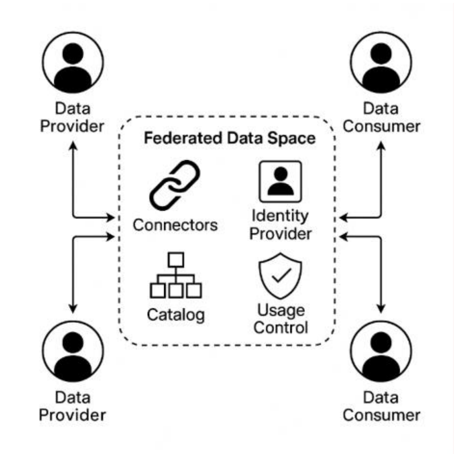

Figure 1: Dataspace Components

In addition to technical interoperability, dataspaces often rely on semantic technologies to ensure consistent interpretation of shared data. Shared vocabularies and machine-readable metadata support integration between heterogeneous systems and domains. This aspect is especially relevant in circular economy scenarios, where lifecycle information, material data, and process descriptions originate from multiple stakeholders and information systems [5].

2.2 Governance, Privacy, and Security

Because dataspaces operate across organizational boundaries, governance, privacy, and security are central requirements. Participants must be able to exchange data without losing control over sensitive or proprietary information. As a result, dataspaces require mechanisms that support trusted collaboration while ensuring compliance with organizational and regulatory constraints [6], [8].

Data sovereignty is one of the main paradigms for dataspaces [3], [8]. It refers to the ability of data providers to control access to their data and define the conditions under which the data may be shared or processed. This is particularly important in CE environments, where lifecycle data may contain confidential business information, supplier relations, or compliance-relevant product details [2], [5].

Security in dataspaces includes authentication, authorization, secure communication, and protection against unauthorized access. Trusted identity management and policy-based access control are therefore essential components of most dataspace architectures [8]. In addition, many approaches support logging and auditing mechanisms to improve traceability and accountability during data exchange processes [8].

Governance defines the rules and responsibilities within a dataspace. This includes participant onboarding, identity verification, semantic alignment, and compliance management [6], [8]. Governance frameworks also support interoperability between organizations by establishing common rules for data sharing and service integration [3], [4].

Kommentiert [ma16]: The image is appropriate in terms of content, but is not currently linked to any text. Please drag it to a suitable location and then add a reference to the image.

Kommentiert [AN17R16]: Done.

Despite these mechanisms, several challenges remain. Organizations may hesitate to share data because of concerns regarding confidentiality, legal liability, or competitive disadvantages [2], [6]. Heterogeneous data models and missing semantic standards can complicate interoperability across domains [5], [6]. A further challenge is policy enforcement, which ensures that shared data is used only for permitted purposes; data providers must be able to specify constraints such as permitted purpose, storage duration, or restrictions on forwarding to third parties. Research indicates that governance must extend beyond technical permissions and incorporate contractual and organizational agreements [3], [6]. How these general challenges manifest in circular economy settings is discussed in Chapter 4.

3 Dataspace Technologies and Architectures

3.1 Solid

Solid (Social Linked Data) is a decentralized data management approach proposed by Tim Berners-Lee to improve data ownership and interoperability on the Web [7]. Instead of storing data in centralized platforms, Solid enables users and organizations to manage their information in personal or organizational data stores called Pods. This architecture allows data providers to retain control over their data while selectively sharing resources with external applications or participants [7], [11].

Solid is based on standard Web technologies and Semantic Web principles. Data should be represented using RDF and Linked Data formats, which support semantic interoperability across distributed systems [7]. This is particularly relevant in circular economy scenarios, where heterogeneous lifecycle data from multiple stakeholders must be integrated and interpreted consistently [5].

The main components of Solid architecture include:

- **Solid Pods** for decentralized data storage
- **WebIDs for participant identification**
- **Web Access Control (WAC)** or Access Control Policies (ACP) for permission management
- **Linked Data technologies** for semantic interoperability

Authentication in Solid is commonly implemented through OpenID Connect (OIDC), while authorization is managed through resource-level access policies [7]. This allows fine-grained control over data access and supports selective data sharing between organizations and users. Fehler! Verweisquelle konnte nicht gefunden werden. illustrates the main architectural components and interactions within the Solid ecosystem.

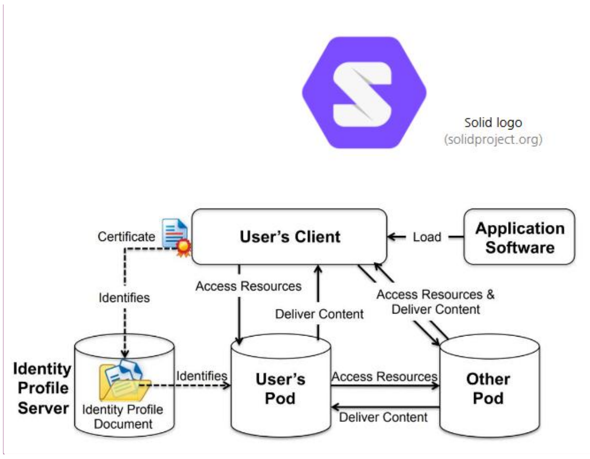

Figure 2: Solid Architecture

One of the main strengths of Solid is its lightweight and modular architecture. Because it is Web-based and open-source, Solid can be integrated relatively smoothly into existing systems and research environments. In addition, its decentralized structure aligns well with CE scenarios that involve distributed stakeholders and cross-organizational data exchange. At the same time, Solid also has limitations. Unlike IDS-based approaches, Solid does not natively provide enforceable usage control, contractual policy management, or integrated auditing mechanisms [8]. Governance and compliance, therefore, often depend on external services or organizational agreements. In addition, the industrial adoption of Solid-based infrastructures is still limited compared to more established enterprise-oriented dataspace solutions.

3.2 IDS-Based Architectures

The International Dataspaces (IDS) initiative defines a reference architecture for secure and sovereign data exchange in industrial environments [8]. Compared to Web-native approaches such as Solid, IDS focuses more strongly on governance, trust, certification, and usage control. The IDS architecture is designed primarily for business-to-business data exchange scenarios that require formal compliance and policy enforcement.

The IDS reference architecture includes several core components:

- **IDS Connectors** for secure data exchange
- **Dynamic Attribute Provisioning Service (DAPS)** for identity verification
- **Metadata Brokers** for dataset discovery
- **Clearing Houses** for transaction logging and auditing
- **Policy enforcement services** for usage control

A central concept in IDS is data usage control. In contrast to conventional access control, usage control defines how data may be processed after access has been granted. Policies may restrict storage duration, forwarding, or the permitted purpose of data usage [8]. This capability is particularly important in industrial ecosystems where data exchange involves contractual obligations or sensitive business information.

Kommentiert [ma18]: Please place this in a more appropriate location

Kommentiert [AN19R18]: Done

Kommentiert [ap20]: Maybe first to CH 3.2 and then CH 3.1 (because you compare Solid to IDS ;)) in CH 3.1

Kommentiert [ap21R20]: ok ... you also compare IDS to Solid in the next chapter ;) so I think its not necessary to change

IDS also defines governance and certification mechanisms to establish trust between participants. Organizations and software components can be certified according to IDS requirements, which improves interoperability and compliance within the ecosystem [8]. These characteristics make IDS-based architecture well-suited for regulated and industrial environments. However, additional governance and security mechanisms also increase architectural complexity and deployment effort. Compared to Solid, IDS-based systems are generally less lightweight and require more infrastructure and operational management.

3.3 Additional Technologies

In addition to Solid and IDS, several other technologies contribute to the broader dataspace ecosystem. It is important to note that these technologies are not interchangeable alternatives addressing the same problem. Rather, they were designed for different purposes and application domains:

Gaia-X is a European initiative that aims to establish a federated and sovereign data infrastructure for cross-sector data exchange. Rather than providing a complete technical platform, Gaia-X mainly defines governance principles, interoperability requirements, and policy frameworks for participating systems [4].

The Eclipse Dataspace Connector (EDC) is an open-source connector framework aligned with IDS and Gaia-X concepts. It supports secure data exchange between organizations and is widely used in industrial data-sharing environments.

FIWARE is an open-source platform that provides middleware and APIs for context-aware data management. It is complemented by the Smart Data Models initiative, which is an open catalogue of harmonized data models covering domains such as smart cities, water, and waste management. These shared models support semantic interoperability and reduce the effort of aligning data between stakeholders. FIWARE is commonly applied in smart-city and public-sector applications.

Kommentiert [ap22]: Maybe we shoud mention the smart data models from FIware for interoperability?

Kommentiert [AN23R22]: Done!

Ocean Protocol is a blockchain-based framework for decentralized data exchange and data monetization. It uses token-based mechanisms to support trusted transactions and data-marketplace scenarios.

IDS targets governed industrial business-to-business exchange, Solid targets decentralized Web-native data ownership, Gaia-X provides a governance and interoperability framework rather than an implementation, EDC offers a connector implementation, FIWARE focuses on context-aware and real-time data management, and Ocean Protocol addresses data commercialization. They are therefore better understood as complementary building blocks with distinct focuses than as competing replacements. These technologies reflect different priorities within the dataspace landscape. Some approaches focus on governance and compliance, while others emphasize decentralization, interoperability, or economic incentives. As a result, no single solution fully addresses all technical and organizational requirements of CE data sharing.

Kommentiert [ap24]: Why do we also highlight solid and ids here. I would first mention the four technologies we want to address, and then write information about them

Kommentiert [AN25R24]: Done!

3.4 Comparative Analysis and Limitations

The discussed technologies differ significantly in terms of architecture, governance, deployment complexity, and support for data sovereignty. IDS-based approaches provide strong governance and usage-control mechanisms, but they also introduce higher operational complexity and infrastructure overhead [8]. Solid, in contrast, offers lightweight and decentralized architecture with strong support for Web standards and flexible deployment [7]. However, it lacks several enterprise-oriented governance features that are available in IDS environments. **Fehler! Verweisquelle konnte nicht gefunden werden.** contrasts the architectural differences between the Solid and IDS-based approaches.

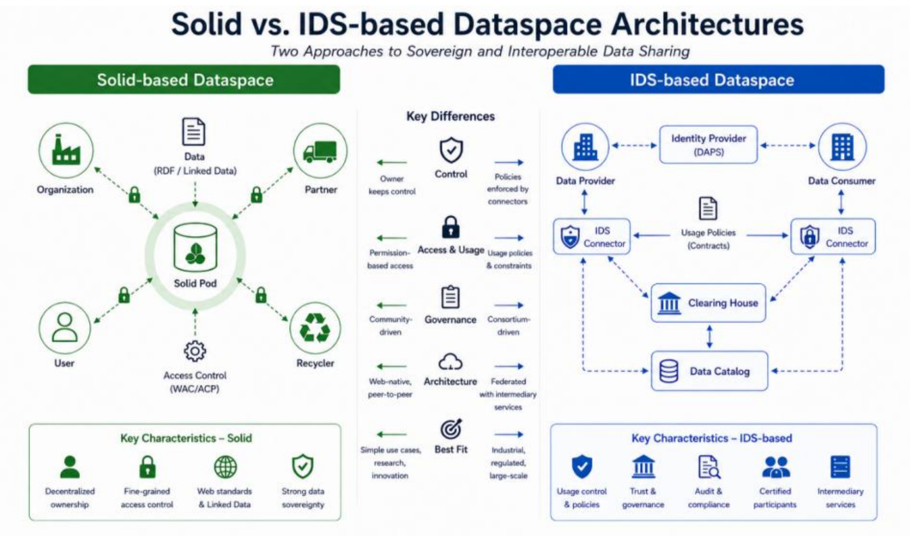

Figure 3: Comparison of Solid and IDS-based dataspace architecture

Gaia-X mainly acts as a governance and interoperability framework rather than a standalone implementation [4]. Technologies such as EDC extend IDS and Gaia-X concepts with practical connector implementations for industrial data exchange. FIWARE and Ocean Protocol address more specialized domains, including context management and decentralized data marketplaces.

These differences mean that the suitability of each technology depends on the specific application context. Among the available approaches, this work focuses on Solid and IDS, as they represent the most widely adopted technologies for dataspaces. Within the IDS strand, the Eclipse Dataspace Connector is considered as an example of one of the most successful implementations following the IDS specifications. The assessment of these technologies against the requirements of circular economy data sharing and the resulting selection for the DACE project is presented in Chapter 5, after the CE requirements have been introduced in Chapter 4. Table 1 summarizes the main characteristics, strengths, and limitations of presented dataspace technologies and highlights the trade-offs between decentralized flexibility and governance-oriented architectures.

Table 1: Comparative Overview of Dataspace Technologies

Technology	Main Characteristics	Strengths	Limitations
IDS-based architectures	Federated industrial dataspace architecture with usage control and certification	Strong governance, policy enforcement, auditing	High complexity and deployment effort
Solid	Decentralized Web-based data architecture using Pods and Linked Data	Lightweight, flexible, strong data ownership	Limited native usage control and governance
Eclipse Dataspace Connector	Open-source connector framework for secure data exchange	Practical industrial integration	Depends on external governance frameworks
Gaia-X	Federated governance and interoperability framework	Cross-sector interoperability and sovereignty concepts	No standalone technical implementation
FIWARE	Middleware platform for context-aware data management	Real-time integration and open APIs	Less focused on data sovereignty
Ocean Protocol	Blockchain-based decentralized data marketplace	Data monetization and decentralized exchange	Additional complexity and limited CE adoption

Kommentiert [ap26]: I'm struggling a bit with this chapter:

I really like the presentation of IDS and Solid. And i also think it is important to Mention Eclipse Dataspace Connector.

But I don't think we need to explain FIWARE, Ocean Protocol and GaiaX. There are a bunch of more technologies out there, and we do not mention them.

So in my opinion, we can just state that we focus on Solid and IDS, because these are the most used technologies for dataspaces so far. And then we integrace the eclipse connector as an example of one most successful implementation in the context of IDS (following the IDS specifications).

And then we remove the other technologies?

Kommentiert [AN27R26]: We have described other technologies briefly and the goal is mentioning most important technologies , but those can also be removed.

4 Dataspace in Circular Economy

4.1 CE Requirements

Kommentiert [ap28]: Would it make sense to give each requirement a number (like we do in software development). This would allow us to reference the requirements more easyily.

So, we number them FR01, FR02 ...

Kommentiert [AN29R28]: Done!

Circular economy processes depend on the availability and exchange of reliable lifecycle data across organizational boundaries [2], [5]. Products, materials, and components pass through multiple stages and stakeholders during their lifecycle, including manufacturers, suppliers, service providers, recyclers, and public authorities. As a result, CE dataspaces must support collaboration between heterogeneous systems while preserving data sovereignty and confidentiality. One important requirement is lifecycle traceability (CE-R01). Stakeholders must be able to access information about product composition, origin, maintenance history, environmental impact, and end-of-life processes [5]. This information is necessary for reuse, repair, remanufacturing, recycling, and sustainability assessment. In addition, recent regulations and initiatives increasingly rely on DPPs, which require interoperable and continuously accessible lifecycle information [4], [6].

Semantic interoperability (CE-R02) is another central requirement. CE-related data often originates from different domains and information systems, which may use incompatible data structures or terminologies. Shared vocabularies and machine-readable metadata are therefore needed to ensure consistent interpretation and integration of data across stakeholders [5], [6]. Selective and controlled data sharing (CE-R03) is also essential in CE environments. Organizations may need to share sustainability indicators, material information, or process data while protecting confidential business knowledge and supplier relationships [2]. Dataspaces must therefore support fine-grained access control and governance mechanisms that allow participants to define how and under which conditions data may be accessed [6], [8].

In addition, CE dataspaces should support distributed and cross-sector collaboration (CE-R04). Circular value chains often span multiple industries and organizational structures. As a result, data-sharing infrastructures must remain flexible and interoperable while supporting different governance models and regulatory requirements [3], [4].

4.2 Challenges and Limitations

Despite recent progress, several technical and organizational challenges still limit the adoption of dataspaces in CE scenarios. While Chapter 2 discussed challenges common to dataspaces in general, this section focuses on the factors that make these challenges more severe in circular value chains, namely the number of independent actors, the length of the product lifecycle, and the regulatory context.

Kommentiert [ap30]: There was already a chapter for challenges above (or a section). I currently don't understand where the difference is (some challenges are identicial, and some not)?

Kommentiert [AN31R30]: Done!
I have changed some parts.
now the section 2.2 covers challenges general to dataspaces and section 4.2 covers why they become harder in CE.

One major challenge is the heterogeneity of data sources and standards. Lifecycle data is often stored in isolated systems with incompatible formats, which complicates interoperability and semantic integration across stakeholders [5], [6].

Data quality and completeness also remain significant concerns. Missing, inconsistent, or outdated information can reduce the reliability of lifecycle assessments and weaken traceability across supply chains [2]. In practice, organizations may collect data using different methods or levels of detail, which further complicates data exchange and interpretation.

Another challenge relates to trust and governance. In CE settings, the data most needed by others, such as material composition, supplier identity, or failure and return rates, is often the same data that constitutes competitive advantage. Unlike customer-facing data sharing, the requesting party is frequently a recycler, remanufacturer, or direct competitor, which increases the perceived risk of disclosure [2], [6]. This makes reluctance to share particularly persistent in industrial CE ecosystems with multiple independent actors in shared value chains.

Policy enforcement and usage control are also difficult to implement consistently in CE environments. Product lifecycles extend over years or decades, so data must remain accessible and governed long after the original data-sharing agreement was made, and often for actors that did not participate in the original transaction. Enforcing usage restrictions across such long time horizons and changing participant constellations remains an open problem [3], [8], and is further complicated by cross-border regulatory requirements.

In addition, governance frameworks for CE dataspaces are still evolving. Current approaches differ in terms of interoperability models, identity management, semantic standards, and compliance mechanisms. As a result, many CE dataspaces still face difficulties regarding scalability, cross-platform integration, and long-term governance [4], [6]. These limitations show that no existing dataspace technology fully satisfies all CE requirements. Different approaches provide different strengths, and practical deployments often require trade-offs between flexibility, governance, interoperability, and operational complexity.

5 DACE Dataspace Approach

5.1 Selection of the Solid-Based Approach

The DACE project required a data-sharing environment that supports decentralized collaboration, semantic interoperability, and controlled access to CE-related data across organizational boundaries. In addition, the selected solution needed to remain flexible enough for research and prototyping activities while supporting practical CE use cases such as lifecycle-data exchange and Digital Product Passports. Based on the previously discussed technologies and requirements, Solid was selected as the primary approach for the DACE dataspace. One important reason for this decision was Solid's decentralized and Web-native architecture [7]. Unlike centralized data platforms, Solid allows organizations to maintain control over their own data while selectively sharing resources with external stakeholders through standardized Web technologies. This aligns well with the requirements of CE environments, where lifecycle data is typically distributed across multiple actors and systems. Another important factor was Solid's support for Semantic Web and Linked Data technologies [7], [11]. CE scenarios often require the integration of heterogeneous datasets originating from different stakeholders, domains, and lifecycle stages. RDF-based data representation and machine-readable metadata therefore provide important advantages for interoperability and semantic integration [5].

Compared to IDS-based architecture, Solid also offers a more lightweight and modular approach. IDS provides strong governance and usage-control capabilities, but it also introduces higher deployment complexity and operational overhead [8]. In addition, during the evaluation phase of the project, no fully mature and complete open-source IDS-based solution could be identified that provided all required components and functionalities in an easily deployable form. Existing implementations often showed limitations regarding connector availability, interoperability between components, configuration complexity, or dependency on partially proprietary ecosystems. These limitations made practical deployment and experimentation more difficult within the scope of the DACE project.

Kommentiert [ap32]: Good :)

For the DACE project, the primary objective was not to establish a fully governed industrial dataspace, but rather to provide a prototypical, flexible, and interoperable environment for CE-related data exchange and experimentation. In this context, Solid provided a suitable balance between decentralization, interoperability, simplicity, and extensibility. At the same time, the selection of Solid also implies several limitations. Native usage-control mechanisms, contractual policy enforcement, and integrated auditing are less developed than in IDS-based approaches [8]. As a result, governance and compliance aspects may require additional external mechanisms in larger industrial deployments. Nevertheless, Solid was considered sufficiently mature and flexible for the requirements and scope of the DACE project. The selected approach reflects a practical trade-off between advanced governance capabilities and architectural simplicity. Rather than attempting to implement a fully comprehensive industrial dataspace framework, the DACE project focuses on establishing a decentralized and interoperable foundation for CE-related data exchange based on open Web technologies.

6 References

[1] „Kreislaufwirtschaft: Definition und Vorteile“, Themen | Europäisches Parlament. Zugegriffen: 5. Januar 2025. [Online]. Verfügbar unter: https://www.europarl.europa.eu/topics/de/article/20151201STO05603/kreislaufwirtschaft-definition-und-vorteile

[2] Serna-Guerrero, R., Ikonen, S., Kallela, O. and Hakanen, E., 2022. Overcoming data gaps for an efficient circular economy: A case study on the battery materials ecosystem. *Journal of Cleaner* Production, 374, p.133984.

[3] Rilling, L., Schneider, A. and Castelli, N., 2023. Towards Dataspaces for circular economy and green business value networks. In EnviroInfo 2023 (pp. 57-68). Gesellschaft für Informatik eV.

[4] Steiner, B. and Münch, C., 2024. Leveraging digital dataspaces in purchasing and supply management: Paving the way to the circular economy exemplified by Catena-X. Journal of Purchasing and Supply Management, 30(4), p.100951.

[5] Pomp, A., Jansen, M., Berg, H. and Meisen, T., 2023, April. SPACE_DS: towards a circular economy dataspace. In Companion Proceedings of the ACM Web Conference 2023 (pp. 1500-1501).

[6] Hofman, W., Rukanova, B., Tan, Y.H., Bharosa, N., Ubacht, J. and Rietveld, E., 2024, March. Digital Infrastructures for Compliance Monitoring of Circular Economy: Requirements for Interoperable Dataspaces. In Future of Information and Communication Conference (pp. 332-351). Cham: Springer Nature Switzerland.

[7] Sambra, A. V., Mansour, E., Hawke, S., Zereba, M., Greco, N., Ghanem, A., ... & Berners-Lee, T. (2016). Solid: a platform for decentralized social applications based on linked data.

[8] International Dataspaces Association (IDSA), “IDS Reference Architecture Model,” Version 4.0, 2020. [Online]. Available: https://internationaldataspaces.org/

[9] Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221–232.

[10] Rosa, P., Sassanelli, C., Urbinati, A., Chiaroni, D., & Terzi, S. (2020). Assessing relations between Circular Economy and Industry 4.0: A systematic literature review. International Journal of Production Research, 58(6), 1662–1687.

[11] Mansour, E., Sambra, A. V., Hawke, S., Zereba, M., Greco, N., Ghanem, A., & Berners-Lee, T. (2016). A demonstration of the Solid platform for social web applications. Proceedings of the 25th International Conference Companion on World Wide Web, 223–226.