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Digital Infrastructures for Compliance Monitoring of Circular Economy: Requirements for Interoperable Data Spaces

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Abstract. The transition towards a circular economy (CE) will require data sharing across different platforms and data spaces of parties operating in a variety of supply chains. From a circular economy compliance monitoring perspective, beyond the access to mandatory data that governments will receive, authorities may benefit from accessing additional business data from the source on a voluntary basis, which is challenging. While platforms and data spaces solve a great deal of complexity and interoperability within their realm, platform, and data space interoperability is still challenging. In the logistics domain, efforts have been made to overcome these issues of data sharing across logistics platforms with a *Semantic data sharing architecture* developed by the CEF FEDeRATED Action, at the heart of which is a semantic model aligning other semantic models for logistics. In this paper, we take the *Semantic data sharing architecture* as a point of departure and examine the opportunities and limitations that it has for CE monitoring, and how it relates to other developments in the EU and beyond. Many of these developments acknowledge the need for data access across heterogeneous systems and – processes of actors; others add security and trust to data sharing that goes all the way to the level to cover legal obligations. The goal of this paper is to gain further insights into how data sharing across multiple platforms and data spaces enables circular economy monitoring, where government organizations would need to address the issue of how they would interface with, and access data that resides in multiple platforms and data spaces. We found that the various models can be aligned on some architecture principles that promote interoperability across dimensions (e.g. federation, keeping data at the source), yet they still differ on other dimensions (e.g. data model and semantics, as well as how they address issues of identification, authentication and authorization). We suggest further efforts towards developing meta-level agreements and standardization for data space interoperability and we propose further research directions on that topic.

Keywords: Data spaces · Platforms · Interoperability · Circular economy · Monitoring · Government

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1 Introduction

Across the globe, governments and businesses pursue circularity as an alternative to the current linear economic model in which quality is still associated with newness and people continue to make, buy, use, and dispose of goods. A circular economy would turn goods that are at the end of their service life into resources for producing other goods, closing loops in industrial ecosystems and minimizing waste[1]. The transition to a circular economy is full of challenges, ranging from geopolitical power-play to consumer behavior. One challenge that received little attention from researchers is data sharing for the circular economy, and the transition will require more fine-grained data sharing across many parties and supply chains that may be disconnected in terms of space and time [16]. For circular economy monitoring, government authorities monitoring cross-border movement of goods, will in the future require access to data that goes beyond the product in a box and in a container and related information about the goods, to include also information about material composition, use, and end-of-life treatment [10].

Developments, such as platforms and data spaces enable inter-organizational data sharing by mobilizing a large number of actors to work together within the realm of agreements of the platform or the data space. However, for circularity, data sharing across data spaces and platforms will be required [7] and governments would need to see whether and how to interface with these multiple platforms or data spaces if they want to use additional business data for their risk management processes.

In the EU, there are important developments[2] such as GAIA-X, International Data Spaces Association (IDSA), CATENA-X, and EU Data Spaces to mention only a few, which also recognize the need for interoperability across platforms and federation. Developments related to eIDAS bring also to the attention the importance of addressing issues of identification, authentication, and authorization, and to go beyond transparency and visibility but to also ensure the data quality to the level that is needed so that this data can be used and stand in court. This form of legal certainty sought using eIDAS trust services is an important aspect to be considered when relying on data sources and evaluating what can be done with them.

For monitoring the circular economy flows, governments will get access to some mandatory data via the government systems, where businesses will be formally obliged to report some data. But in the business systems, there is much more data that can be useful for the government for CE-monitoring purposes if shared on a voluntary basis in exchange for business benefits such as trade facilitation in return.

The challenge to achieve which are as follows:

1) For circular economy monitoring, government authorities need to get access to data across platforms (data spaces) and the issue is how to access this data.
2) Authorities need to access many different data spaces and platforms to have access to the data, so it will not connect to each and every one of them in a different way, a standardized way is needed.

[1] See e.g. the conceptualization from the Ellen MacArthur foundation regarding the circular economy flows https://ellenmacarthurfoundation.org/circular-economy-diagram.

[2] We will introduce them more thoroughly later in this paper.

3) The data quality and legal status of the data accessed is weak if the data source does not provide a form of assurance that it is actually the data source.

The goal of this paper is to identify opportunities related to data space interoperability and how data sharing across multiple platforms and data spaces can be realized to enable circular economy monitoring by authorities. As an empirical context, we take the FEDeRATED *Semantic data sharing architecture* as a point of departure. This semantic data sharing architecture aims to address data space interoperability in the logistics domain and how governments can access such data by making use of a semantic model, containing an upper ontology that is aligned with a logistic ontology. Taking the *Semantic data sharing architecture* and reflecting on how it relates to the other developments related to data spaces and data space interoperability, it is possible for us to gain insights into the kinds of challenges and questions that need to be addressed to achieve interoperability across platforms and data spaces to enable circular economy monitoring by government.

2 Digital Trade Infrastructures and Digital Infrastructures for Circular Economy Monitoring

In the international trade domain, earlier e-government research has examined the potential of using digital infrastructures for getting access to business data from the source (shared on voluntary basis) for government control purposes when it comes to safety and security risk assessment and revenue collection related to international trade flows [3–6, 9, 11, 13, 15]. These studies have examined different aspects that shed light into the complexities of using such infrastructures for government control purposes. For example, Rukanova et al. [9] developed a framework that provides a further understanding of digital trade infrastructures, by looking at dimensions like (a) architecture, (b) process, and (c) governance. Studies have also focused on providing a broader vision of government control approaches that rely on the differentiation of trusted traders and trusted trade lanes and less trusted ones [4], on what complexities need to be overcome when coming to voluntary business-government data sharing [10, 12] and how the technical design choices of the data sharing infrastructure also play a role in the decision-making process related to data sharing [16]. While these studies bring a lot of insights, the focus of the analysis was often limited to the exporter and importer in the country of origin and destination and (containerized) cargo that is imported. Little attention was paid to the material/chemical composition of the cargo, their production process, or the way products were used or disposed of at the end of life. These aspects were identified as important to consider when examining the potential of extending digital trade infrastructures and how they can be used for government control purposes for circular economy monitoring [10].

To better understand challenges related to using digital infrastructures for circular economy monitoring purposes, [7] developed a *Circular economy visibility evaluation framework*. This research shows that for circular economy monitoring, data is likely to reside in different platforms and reflect different levels of granularity. The challenge that, for circular economy monitoring, it is likely that the information will be dispersed in multiple platforms of different supply chains is also pointed out [16]. Earlier research

[7] shows that when moving from individual items to boxes and containers the visibility is obscured. The study [7] examines different blockchain platforms and show how these can provide (partial) visibility for circular economy monitoring, and that by having access to different platforms additional visibility on the circular economy flows can be obtained. However, in [7] the issue of platform interoperability is only mentioned but not further elaborated. It is assumed that the data can be pulled from the different infrastructures for circular economy monitoring purposes, and issues like interoperability between platforms and how to address challenges related to semantics and governance of data access are not addressed.

Interoperability, from a technical perspective, has been defined by IEEE as the ability of two or more systems or components to exchange information and to use the information that has been exchanged [18]. Over the years other levels beyond technical interoperability have been introduced. The European Interoperability Framework[3], next to the technical and semantic level also includes organizational and legal interoperability levels. In the past, in the context of inter-organizational systems, interoperability was focused on achieving interoperability between two or more organizations. The world has evolved since then and digital platforms, digital infrastructures, and data spaces allow now for a way for a large number of companies to connect and be interoperable and share data facilitated by the platform or the rules set in a data space. A data space can be seen as "a federated, open infrastructure for sovereign data, sharing, based on common policies, rules and standards"[4]. When exchanging data within a platform and in a data space many interoperability levels are well addressed. The issue is when more than one platform or data spaces are considered, how can interoperability be achieved?

Some initial work to address data space interoperability in relation to the FEDeRATED semantic data sharing approach is already underway in the context of data sharing and the potential it has for the Physical Internet [19]. Conceptually, the study [19] builds on the levels of conceptual interoperability model that has been developed in earlier research [14, 17] as a starting point to reflect on interoperability across data spaces as well. The model of conceptual interoperability [14, 17] is interesting, as next to the technical (level 1), syntactic (level 2), and semantic (level 3) interoperability, it includes also higher levels such as pragmatic (level 4), dynamic (level 5) and conceptual (level 6) interoperability. These higher levels refer to the awareness of the context (system states and processes) and use of the data (pragmatics), the ability to re-orient information production based on changing meaning due to changing context over time (dynamic interoperability), and conceptual interoperability (level 6) where systems are completely aware of each other's information. The study [19] discusses that taking interoperability models that address the higher levels all the way to conceptual interoperability and considering legal interoperability, would form a good basis for reasoning about what are missing points and how they can be addressed to achieve data space interoperability as well.

[3] https://ec.europa.eu/isa2/sites/default/files/eif_brochure_final.pdf.

[4] Gaia-X White paper (2022), What is a data space, Definition of the concept data space, available at: https://gaia-x-hub.de/wp-content/uploads/2022/10/White_Paper_Definition_Dataspace_EN.pdf.

The stream of research on digital infrastructures for circular economy monitoring that we discussed above stems from research in the international trade domains and how digital infrastructures can be used for government monitoring, where business data from the source is made available to government authorities on a voluntary basis. At the same time, we also observe other developments stemming from circularity which are reflected in the policy and regulatory context. One such development is the Digital Product Passport. A Digital Product Passport (DPP) can be seen as "a structured collection of product-related data with pre-defined scope and agreed data ownership and access rights conveyed through a unique identifier and that is accessible via electronic means through a data carrier"[5]. The intended scope of the DPP is information related to sustainability, circularity, value retention for re-use, remanufacturing, and recycling. Reflecting on the monitoring by authorities, disclosing some of the product passport-relevant information is likely to be required by law and businesses will be mandated to provide such data to the authorities. But beyond the data mandated by law, there will be a wealth of additional data that may potentially be useful for governments for their risk assessment processes related to circularity in the context of public-private partnership models such as the trusted trade lanes discussed earlier. Not only customs but also other government agencies that have a very strong role in circular economy monitoring (such as market surveillance authorities) may benefit from such additional information provided on a voluntary basis. But also some of the mandatory data is likely to remain in the business systems and governments would need to get access to it.

The digital product passports are still under development and work is underway (see e.g. the Multi-country Flagship Workshop on Digital Product Passport implementation[6], the CIRPASS[7] project, as well as early publications on the topic, e.g. [1, 2, 8]. In the coming period, it is expected to have more clarity on how digital product passports will shape both in terms of data contained in the passports, as well as the technical architecture that will support the data sharing.

Taking a government perspective, the circular economy is yet another concern for the government in monitoring international trade flows, next to other concerns such as revenue collection and safety and security [12]. When looking into investments that governments will need to make if they want to access additional data sources for government control purposes, and in the future also mandatory digital product passport data, it may be desirable to take an integral perspective, meaning not to invest in separate systems to interface with the business infrastructures for each individual concern (e.g. safety and security, fiscal, circularity) but to use the same infrastructure to connect to access (voluntary) business data of various supply chains, especially as governments may need information from the same supply chain parties with respect to different government concerns.

[5] For DPP we adopt the definition provided by the CIRPASS project, https://cirpassproject.eu/faq/.

[6] https://webgate.ec.europa.eu/TMSWebRestrict/resources/js/app/#/library/detail/82455.

[7] https://cirpassproject.eu/.

3 Method

To gain a further understanding of how governments can use data from different digital infrastructures that may hold circular economy-relevant data, we conduct a case study in the context of the DATAPIPE[8] project and the use of the *Semantic data sharing architecture* developed in the FEdeRATED project as a point of departure. The DATAPIPE project aims to examine the potential of digital infrastructures for circular economy monitoring. In DATAPIPE, the potential of the Semantic data sharing architecture developed in FEDeRATED is examined, to investigate how it may allow for a federation of network of platforms to allow access to data relevant for circular economy monitoring context.

As a starting point, we introduce the *Semantic data architecture* and then we reflect on how it relates to other approaches that we see emerging in practice. The Semantic data sharing architecture is developed by the CEF[9] FEDeRATED[10] Action to enable logistics data sharing among various platforms and stakeholders. This constitutes a so-called 'federated network of platforms' (as considered by the Digital Transport and Logistics Forum, DTLF[11]) or Mobility Data Space (for freight). Government authorities (customs) are also potential users and they can use this information for monitoring purposes. At the heart of the *Semantic data-sharing architecture* is the semantic model, which consists of an upper-level ontology that is used for alignment of mode, cargo, document, and/or physical infrastructure ontologies. It allows parties to share information using common semantics as defined by these aligned ontologies without any prior agreement on which data to share ('plug and play'). The data-sharing architecture is developed and validated with various Living Labs in different EU Member States. The results of the CEF FEDeRATED Action are to be adopted as recommendations to the European Commission Directorate-General MOVE for the Mobility Data Space by the Digital Transport and Logistics Forum (DTLF). DTLF is an expert group of Member State authorities, Industry Associations, standardization bodies, data-sharing platforms, and individual enterprises raised and chaired by DG MOVE[12] of the European Commission. Research on how the semantic model can be aligned to allow for data sharing on products and materials in the circular economy monitoring is now taking place as part of the DATAPIPE project.

At the same time, we also see a dynamic environment of policies and instruments that are constantly changing and evolving and it is not always easy to understand how they relate. For example, we see developments related to public EU policy agendas (EU Data Strategy driven by EC DGs CONNECT[13], private policy agendas like those

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8 https://www.tudelft.nl/datapipe.
9 Connected Europe Facility.
10 http://federatedplatforms.eu/.
11 https://transport.ec.europa.eu/transport-themes/digital-transport-and-logistics-forum-dtlf_en.
12 https://commission.europa.eu/about-european-commission/departments-and-executive-agencies/mobility-and-transport_en.
13 https://commission.europa.eu/about-european-commission/departments-and-executive-agencies/communications-networks-content-and-technology_en.

of the German Industry (IDSA[14] – International Data Space Association and GAIA-X[15], and related GAIA-X Federation Services (GXFS)[16], and specific implementations as part of the lighthouse projects[17] like CATENA-X[18] in automotive) collaborating with the Big Data Value Association and the FIWARE foundation into the Alliance to Accelerate Business Transformation in the Data Economy, and global developments by for instance the World Economic Forum (WEF). Other developments like European Blockchain Services Infrastructure (EBSI)[19], eIDAS[20] for electronic identification and trust services, and W3C Verifiable Credentials[21] are also gaining attention. All these developments are ongoing, next to other international industry solutions, and an issue is how to make sense of these developments and how to allow for this diversity but still allow for data sharing across platforms and data spaces that make choices to commit to one approach or another.

To gain a conceptual understanding, in our case study, we take a focused approach and focus on discussing the *Semantic data-sharing architecture* in relation to these other developments. Rather than comparing this architecture to each of the initiatives individually, we step on the findings from the Horizon 2020 Open DEI project[22] which examines many of these initiatives and defined building blocks. We use these building blocks to discuss the *Semantic data sharing architecture* as well.

Subsequently, we zoom in and discuss two aspects related to interoperability between platforms and data spaces that are relevant for circular economy monitoring when it comes to accessing data that resides in different platforms, namely the *(1) aspect of semantics*, and *(2) the aspect of data access,* and we reflect on these aspects taking the other developments into account. Specifically for the second aspect we also examine developments related to eIDAS, especially the first version (Regulation No 910/2014), since the second version is still under revision. The second version is expected to establish guidelines for using data wallets, and verifiable credentials define the structure of the data. While eIDAS is limited to the European context and still has limited applications (e.g. signing, sealing, exchange, and archiving) it creates an EU-wide legal foundation for developing agreements on mandatory and voluntary data exchange. Therefore, businesses and government agencies do not have to figure out how to develop and monitor these kinds of trust services or rely on proprietary platform authentication schemes.

[14] https://internationaldataspaces.org/.
[15] https://gaia-x.eu/.
[16] https://www.gxfs.eu/.
[17] https://gaia-x.eu/who-we-are/lighthouse-projects/.
[18] https://catena-x.net/en.
[19] https://ec.europa.eu/digital-building-blocks/wikis/display/EBSI/Home.
[20] https://digital-strategy.ec.europa.eu/en/policies/eidas-regulation.
[21] https://www.w3.org/TR/vc-data-model/.
[22] https://www.opendei.eu/.

4 Semantic Data Sharing Architecture for Circular Economy

In this section we first introduce the key concepts related to the *Semantic data sharing architecture* as developed in the CEF FEDeRATED action (explained below). We then discuss how this architecture that was originally developed for data sharing of logistics data can be applied in the context of circular economy monitoring.

4.1 The Semantic Data Sharing Architecture as Developed in FEDeRATED

As part of the Mobility Data Space development, a Semantic data sharing architecture has been developed, prototyped, and validated by the CEF FEDeRATED Action. This has been adopted by the Digital Transport and Logistics Forum (DTLF), an expert group raised and shared by EC DG Move. One of the pillars of the Digital Transport Strategy of the Dutch Governments is the development of a Basic Data sharing Infrastructure (BDI[23]) according to this architecture in the Data Infrastructure Logistics (DIL) project. Other initiatives like Santana (Hamburg Port Authority and Dakosy), H2020 Magpie (Rotterdam Port Authority), Nexus (Port Authority of Sines), and PILL (Imec and Free University of Brussels) have similar objectives for realizing a data sharing infrastructure according to the Semantic data sharing architecture or aligned architectures. The various results of the CEF FEDeRATED Action can be found at the FEDeRATED product portal[24].

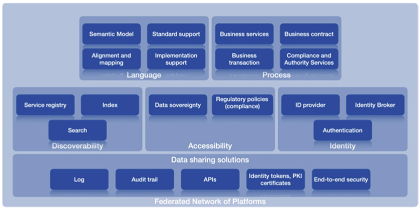
Figure 1 provides a snapshot of the Semantic data sharing architecture and models of the FEDeRATED semantic data sharing architecture that we use for our case analysis. We briefly explain these below. Further information about the FEDeRATED architecture and the related models can be found on the website of FEDeRATED, as well as in [19]. Here we introduce basic concepts in order to be able to relate to these with examples when we discuss the context of circular economy monitoring.

In short, the Semantic data sharing architecture consists of three layers, namely (1) the conceptual layer specifying semantics and business process collaboration and compliance, (2) the functional layer, and (3) a data-sharing layer. The data sharing layer basically contains functionality for sharing any type of data and provides functionality like non-repudiation, safe, secure, and reliable data sharing as shown by the protocol stack. The protocol stack shows that only links to data are shared; this is via the 'event' concept (see further). Conceptually and functionally the semantic model, Service Registry, Index, and Identity and Authentication (IA) are distinguished. Access policies relate to business activities and regulations for monitoring them as we will explain.

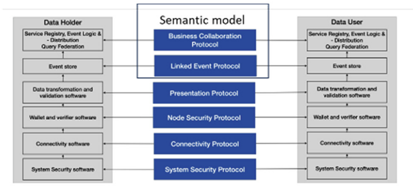
Identity and Authentication separates trust of individual organizations, meaning they have implemented cyber security and quality measures for trust, and interorganizational trust. Interorganizational trust can be supported by Verifiable Credentials (VCs) implementing peer-to-peer trust issued to individual organizations according to certification and agreed internal trust framework. These VCs contain identification and that part of the concept that is applicable for an organization. The latter is called 'organization profile'

[23] See e.g. https://topsectorlogistiek.nl/wp-content/uploads/2022/07/20220614-BDI-Intro-FAQ-ENG.pdf.

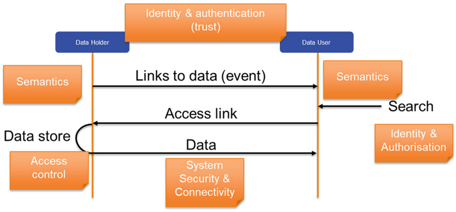
[24] https://federatedplatforms.eu/index.php/products.



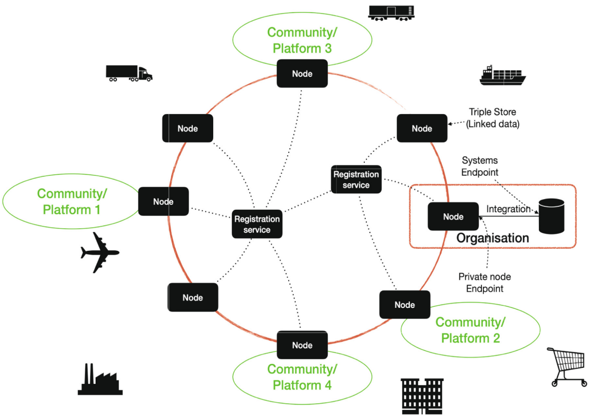
a. Data sharing architecture



b. Protocol stack

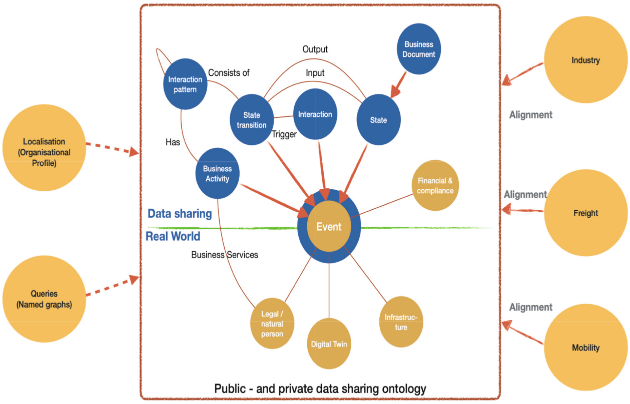


c. Linked data



d. Federated network of platforms or nodes

Fig. 1. A snapshot of the Semantic data sharing architecture and related models (Further information can be found at http://federatedplatforms.eu/, as well as Hofman et al. (2023).)



e. Alignment structure

Fig. 1. (*continued*)

VCs and will be stored in a wallet, whereby particular roles in an organization will be authorized to use that wallet.

The other elements are closely interrelated as will be explained. The semantic model is an upper-level ontology for aligning the different ontology models, documents, and physical infrastructure ontologies. An upper ontology contains those *concepts* and *properties* that are common to the ontologies that it aligns supporting business. Alignment is a 'join' of two or more ontologies. To enable alignment, the '*Digital Twin'* and *'event'* concept are introduced, where a *taxonomy* of *Digital Twins* is given.

To assure seamless data sharing, i.e., data sharing without any prior agreement on which data to share, a data sharing ontology is developed. The data-sharing ontology contains concepts for specifying a so-called Business Process Modeling Notation (BPMn2.0) choreography for business *activities* and *compliance*. These concepts are subtypes of 'event'. Any designer can thus construct what are called interaction patterns for business activities. *Transport*, *production*, *assemblage*, and *storage* are examples of *business activities*. *Booking*, *ordering*, *visibility*, and *payment* are examples of *interaction patterns*. These *business activities* and *patterns* specify minimal data that must be shared and/or accessible. These minimal data sets can contain options, like at least a subtype of a Digital Twin supertype must be available. This subtype can be selected by an enterprise for configuring its profile. Thus, access policies are formulated.

Moving further with describing the Semantic data sharing approach, the objective of the Service Registry is to support organizations to develop and publish their business services for business activities. As such, these business activities and interaction patterns need to be designed and a user of the Service Registry must be able to select its applicable elements of business activities (e.g. production). Any design of a business activity and its interaction pattern are constraints to the semantic model, represented by SHACL (SHApe Constraint Language). 'Cargo' is for example a constraint listing all the subtypes of Digital Twins that can be carried by or packed into other Digital Twins (e.g., pallets in containers, containers on trailers, and trailers on wagons). Any selection by a user to make them applicable provides more constraints, e.g., a user may only support containers as cargo. These constraints are the basis for data validation and event logic, functionality specified as Index. The latter can be implemented by a triple store, which stores events with links to data as triples (RDF[25]) and implements the semantic model (and its aligned models), integrating with existing IT systems (via a semantic adapter), and supporting data quality validation, event logic, and query federation (data provenance). Events with links to data are part of authorization: someone that has received a link is authorized to evaluate that link and get access to data according to agreed access policies specified for business activities and their supporting interaction patterns.

To allow for migration and adoption, the Service Registry will generate openAPIs[26] with JSON. To achieve seamless interoperability, organizations must implement business activity interaction patterns with a technology of choice. An implementation with semantic technology is expected to provide more flexibility and extendibility than a (traditional) API or messaging-based implementation. As part of the business collaboration protocol, data-sharing agreements are shared resulting in digitization of part or all the business activity interaction patterns.

4.2 Applying the Architecture to Circularity

Circularity refers to manufactured products or parts, which are of course not yet modelled by the DTLF model. Let us take the circular economy monitoring of, for instance a car, to reflect how these concepts that are developed for logistics may be applicable. For example, the car is an object represented as a sub-type of a digital twin. The digital twin has data properties relevant for sharing with business stakeholder. In the data-sharing environment, all objects have a Universal Unique Identifier (UUID)[27]. A car will have a UUID X and it consists of numerous components (e.g. a gearbox) and each such component has a separate UUID Y. When a car is manufactured or produced (*business activity* in terms of the semantic data sharing approach), the components are put together in a very specific sequence at different moments in time and each of these moments are manufacturing *events (event* concept in terms of the semantic data sharing approach). Every component will have a UUID. If you have a problem with a component in a car that comes from a specific supplier, you can use the UUID of the component to go to the website of the supplier to get information. Each batch consists of several UUIDs. Car is an object and has components (e.g. a gearbox). *Event* is that at a certain moment in time these elements are in the car. *Event* can be a manufacturing event (gearbox put on a car). From a circular economy point of view, all attributes are specific event, and if an event is coming at a later point in time, the same thing can be represented with different events, allowing to capture changes. If we are at the planning stage, the planning aspect can be to ensure that you have sufficient components to make the car. Events can also reflect design choices. An *event* can indicate that wires are included in the plastic to produce a certain part. If later on new designs are made to produce that part only by using plastic and no wires, we will then have an event that there are no wires. This shows how the ontology, which was originally developed as an upper-level ontology to

[25] Resource Description Framework.
[26] Application Programing Interface.
[27] https://www.uuidtools.com/what-is-uuid.

describe elements relevant for data sharing for logics data spaces[28] can be also used in the context of circular economy (like the example with the car).

5 Discussion

In Fig. 2 below we use the model of conceptual interoperability to reflect on data space interoperability. For CE monitoring we are interested in how government authorities can access data that resides in multiple platforms and data spaces, therefore the figure also explicitly includes government.

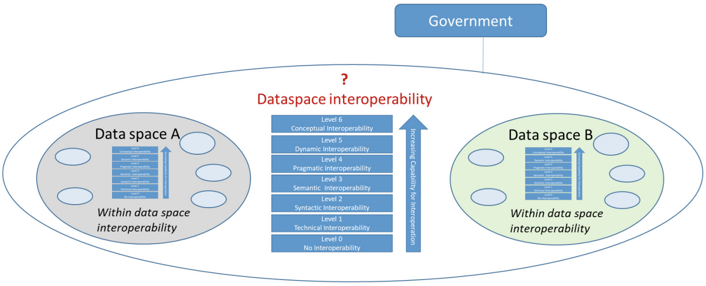


Fig. 2. The issue of data space interoperability

When it comes to a specific platform or specific data space these levels of interoperability are well covered as within these platforms and data spaces parties are able to share data. In Fig. 2 we also positioned the levels of interoperability between data spaces, to allow us to reason about the interoperability challenges that need to be overcome when accessing data across data spaces.

Open standards of lower layer protocols can still lead to non-interoperable data spaces which create difficulties for sharing the information across data spaces. For example, the IDSA – and Eclipse Data space Components (EDC) aims to be both implementations of the same protocol but are not interoperable. Some software components also implement functionality of more than one protocol layer, slightly different from each other. For instance, an IDSA connector supports integration with a data broker acting as Service Registry but in a data agnostic way. These differences signal interoperability challenges that need to be tackled to overcome the lower levels related to technical interoperability.

But beyond the technical levels, this lack of interoperability is also when it comes to semantics, identification, and authentication. Within the realm of a specific data space, using a common ontology in a data space and having registries where everybody knows

[28] e.g. in the car example we use the same concepts from the upper level ontology to describe how a gear box is linked to the car during the production process and these concepts are traditionally developed for logistics events (e.g. a container with specific UUID X and a vessel with specific UUID Y and when the container is put on a vessel, this is an event linking the specific container with UUID X and the specific vessel with UUID Y at specific time. And then the vessel has all UUID of the containers that are on that vessel).

who the data holder and the data user are, is useful. But how do you access data if you are not part of the registry; and for governments, do they need to become registered and members of each data space? And the same for businesses that need to access data across data spaces.

As we see now, but it may be that the situation will remain in the future, there will be a diversity of approaches that will exist. But the question is how to make steps to allow for this diversity but at the same time create room for data sharing and interoperability across data spaces and solutions. One option to go beyond the closed data spaces is to start making agreements for data space interoperability. This would mean having some common agreements of how to go about with semantics and having some common agreements and alignment on how to deal with identification, authentication, and access policies. But what can be done and what agreements need to be made in the cross-data space realm? Below we reflect on these issues by looking at the semantics (Sect. 4.1), and at the identity and authentication (Sect. 4.2). But before doing that we will first reflect on the Semantic data sharing architecture that is at the center of our analysis, in relation to the other approaches we discussed.

In the next pages, a data space and a platform are synonyms. A data space with its own governance structure may have implemented a platform and a commercial platform provider enables its own or one or more other data spaces.

5.1 Reflection with Respect to Other Related Initiatives and Related Key Concepts

In order to be able to reflect how the Semantic data sharing approach developed in FEDeRATED relates to other approaches, we make use of the H2020 Open DEI project building blocks. The H2020 Open DEI project has developed a set of common building blocks for data sharing, based on input of various private initiatives like IDSA, GAIA-X, FIWARE foundation, and iSHARE foundation[29].

These building blocks and solutions developed by the private sector do not address quires some type of open system. This is particularly relevant in the context of circular the public sector interface that is supported by the DTLF. Including compliance re economy monitoring, where governments will need to access CE-relevant data for monitoring purposes.

Open DEI distinguishes design principles and building blocks. The assumption is that the design principles and building blocks align all relevant initiatives that collaborated. A comparison of the design principles is given in Table 1, showing the Open DEI design principles are applicable to 'data' in the broadest sense, whereas FEDeRATED/DTLF considers commercial transactions and compliance with regulations for multimodal transport.

While the detailed mapping to the approach and building blocks goes in great levels of technical detail which we do not include here, on a high level one main observation is that commonly agreed principles can be based on generic building blocks as part of the design principles 'soft infrastructure'. However, although many building blocks

[29] https://ishare.eu/.

Table 1. Open DEI and FEDeRATED/ DTLF approach

Open DEI		FEDeRATED/DTLF	
Principle	Description	Principle	Comment
Data sovereignty	The capability of a natural person or a corporate entity for exclusive self-determination with regards to its economic data goods	Supported, also addressing authorities	Data is considered in a commercial transactional – and legal, compliance context. eIDAS seeks to promote digital sovereignty and trusted data sharing in the EU
Data level playing field	No insurmountable barriers for new entrants	Level playing field at business level	A special focus on the capability of all enterprises to participate. This will be achieved via 'plug and play' at business level
Decentralized soft infrastructure	How to use existing – and new infrastructures based on functional, technical, operational, and legal agreements	Federated network of platforms	Existing solutions, platforms, and standards must be supported to create a federated network of platforms. This is basically achieved by creating a protocol stack as output of DTLF
Public-private governance	Governance by all relevant stakeholders is essential	Fully supported	So-called Industry Associations are considered as key for realizing success, since these are channels to industry stakeholders

are common to different data-sharing architectures, their implementation can differ. As such, open standards can still lead to non-interoperable data spaces.

5.2 Addressing Data Space Interoperability Challenges at the Higher Interoperability Levels

Open standards and their implementations can still lead to closed data spaces which create difficulties for sharing the information across data spaces when it comes to semantics. Data space approaches like IDSA and Gaia-X all refer to semantics but still support data duplication with messages and/or APIs. They lack a common model of data sharing functionality and the generic upper ontology structure with a taxonomy of Digital Twins and events as specified by the FEDeRATED multimodal data sharing ontology as explained earlier. Their individual interactions with their semantics (messages/APIs) can be aligned with the FEDeRATED ontology.

Thus, the creation of data space interoperability requires the following approach:

- **Alignment** – The functionality of a data space is aligned with the upper ontology. In case the upper ontology lacks functionality provided by a lower ontology, it can remain specific to that lower ontology, or a decision can be made to extend the upper ontology if that functionality is considered to serve a broader purpose. Alignment includes the selection of one or more concepts of the data sharing ontology, which may already have been specialized.
- **Publication** – All participants of a data space must be discoverable outside that data space, including their functionality as aligned with the upper ontology.
- **Lower layer protocols** – The lower layer protocols and their interoperable implementations must be selected to enable actual data sharing at business level. These include the presentation - (syntactic), node security - (this will be discussed hereafter), connectivity, and system security protocol. Each data space may thus implement their own lower layer protocols but can share data with other data spaces via a gateway.

This proposed approach allows each data space to make its own agreements and be interoperable with others. Thus, distributed development and implementation is feasible, where data space interoperability requires a uniform protocol stack implemented by all participants. It may require additional functionality of a data space, for instance the support of semantic web standards and knowledge of the upper ontology for creating alignment. Having such an upper ontology implies governance and standardization.

By using the visualization of [19], it is possible to show a transition from closed data spaces to open neutral data sharing infrastructure. This approach is required by authorities implementing regulations, where all stakeholders interact in the same way with those authorities. This is particularly relevant for CE monitoring for governments accessing business data from different supply chains and industries.

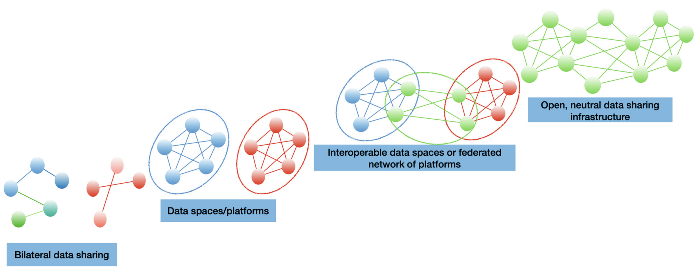


Fig. 3. Transition phases from data spaces/platforms towards an open, neutral data sharing infrastructure (adopted from [19])

The objective of the Mobility Data Space, however, is to move towards an even more open environment and implement the right picture of Fig. 3, which creates an open, flexible and extendible data sharing infrastructure. This move towards the right picture is under development, and expected to be a blueprint for the mobility data space. And what it aims is to explore, in the DATAPIPE project, and to investigate whether this same approach that is developed for mobility can be used in other contexts, i.e. the context of circular economy monitoring.

Adopting the upper ontology for the circular economy, which has its own data requirements and – capabilities, may require the development of a lower ontology with the inclusion of new concepts in the upper ontology. For instance, the concept ‘business activity’ could have a subtype for ‘production/manufacturing’, the Digital Twin taxonomy can be extended by subtyping ‘product’, and ‘event’ may require additional data properties for the new subtypes of ‘business activity’.

To address semantic and pragmatic interoperability that is needed in the context of data sharing for CE monitoring, a possible way forward is to start making agreements about the meta-level descriptions. These agreements about the meta-level can be standardized:

- **Business data sharing ontology** – the upper ontology for data sharing supporting business activities and compliance with concepts like Digital Twins, events, states, and state transitions.
- **Interaction patterns** – a set of interaction patterns to support commercial transactions or compliance-based data sharing that specify access control policies.
- **Linked Event Protocol** – the way of sharing events with links to data.

Assessing these aspects may facilitate access to data from various platforms and data spaces for CE monitoring purposes.

5.3 Interoperability Challenges for Identification and Authentication

Each data space most probably has implemented its own identification and authentication scheme, for instance, blockchain-based data spaces. The same is applicable for other data spaces. Mostly they may have only implemented a system security protocol like TLS[30] and, due to various private rules, not any other mechanism. However, data space interoperability requires another approach where identity of a user of one data space can be authenticated by a user in another data space. In this case, also a gateway solution can be developed, like done for blockchain-based data spaces, but such a solution is not scalable.

Identity and authentication are relevant to all users but in the context of CE monitoring is a bigger issue for authorities that need to integrate with many private data spaces. To address this issue, most authorities specify and enforce their requirements on those private data spaces by law. This will impose more costs (initial investment and operational) on these private data spaces. To avoid these additional costs for private data spaces and to address scalability of data spaces interoperability, W3C has developed standards for Decentralized Identifiers (DID[31]) and Verifiable Credentials (VCs). Originally, these concepts stem from blockchain initiatives with their wallets like SSI (Self

[30] Transport Layer Security protocol.
[31] www.w3.org/TR/did-core/.

Sovereign Identities) that have been proposed as standards for scalability. Yet, there are no implementations of interoperable wallets or the use of multiple wallets by a data holder with standardized interfaces to data issuers and – verifiers. These standards for VCs and DIDs are agnostic of any data contained by them, a VC can for instance represent details of a private person like its driver's license, age, etc., its authorization as an employee of an organization, and an electronic business document like an eCMR[32] or a Digital Product Passport. In this context, an upper – and its lower ontologies can play an important role.

At EU level the EBSI is also piloting this approach, and it holds promise also in the context of Digital Product Passports. It will be important to further monitor how the use of this approach will shape and develop. At the same time, at the EU level we also see the development of trust frameworks like eIDAS, which go further than verifiability but go into the legal status and the legal frameworks that apply and who are trust anchors that are recognized by law and who are legally allowed to sign. While eIDAS is only an EU development and initially developed with more limited applications for citizen and business interactions with the government, its scope is now being expanded in eIDAS 2 combining wallets and EBSI and in the future may provide interesting new insights regarding agreements that need to be reached that take also the legal liability and legal certainty for data sharing parties into account. Some pilots with VCs, EBSI, and NFTs (Non-Fungible Tokens) for authentication of products are underway with the first application for incoming cargo via air, based on IATA OneRecord[33] APIs.

5.4 Research Directions for Digital Infrastructures for Circular Economy Monitoring with a Focus on Data Space Interoperability

The issue of data space interoperability and how government authorities can access them for circular economy monitoring is just starting to gain attention. Based on the issues discussed earlier, in Table 2 below we outline several topics and research questions that can serve as research directions on the topic for further research in the area of data space interoperability.

While these questions are formulated in a general sense, we are interested in them from the point of view of data space interoperability for CE monitoring purposes to drive our further understanding on the topic.

32 https://www.iru.org/what-we-do/facilitating-trade-and-transit/e-cmr.

33 https://www.iata.org/en/programs/cargo/e/one-record/.

Table 2. Further research directions related to data space interoperability

Topics	Research questions in the area of dataspace interoperability for CE monitoring
Semantics/data sharing ontology	What needs to be standardized and what is subject to governance? What are the governance rules, concepts, and procedures for distributed development? Who should participate in a governance body and who is responsible for developing lower ontologies on behalf of an industry or government? How to create alignment with existing data spaces and platforms? What is the minimal required functionality to achieve conceptual interoperability and how can we get it implemented?
Identification, authentication, and authorization (IAA)	How do we organize identity matching and authentication across data spaces? Which identifiers are trustworthy on a cross-domain level for products/materials, actors and services? Can we embrace eIDAS-qualified trust services providers and trust services in the variety of digital infrastructures in a global context? What is the role of standards to create an open environment for trustworthy digital product passports? How to apply Verifiable Credentials and Decentralized Identities in this context? Can we specify access policies and authorization based on business activities and linked (event) data?
Market power and the role of government	What standards are required for data space interoperability (see the proposed FEDeRATED protocol stack)? What can be the role of the semantic web stack? What are relevant standardization bodies? Are different parties likely to take a lead for the standards at the different levels and for which levels and at which level governments may have a role? What is the role of market power for the standard adoption?

6 Conclusions

Many companies are investing in traceability solutions. The transition towards a circular economy will require data sharing across different platforms and data spaces of parties operating in a variety of supply chains that span from the production supply chain using raw materials for production, to consumers, prolonged use and repair, to supply chains handling the end-of-life treatment and recycling and regaining materials back to new production processes. From a circular economy monitoring perspective, beyond the access to mandatory data that governments will receive, authorities may benefit from accessing additional business data from the source shared on a voluntary basis. However, accessing data relevant to circular economy monitoring that resides in multiple platforms is challenging. While with the developments of platforms and data spaces, a great deal of complexity and interoperability is solved within the realm of a platform and data space arrangements, accessing data and achieving interoperability across platforms and data spaces is challenging. By taking the semantic data sharing approach as developed in the FEDeRATED project as a starting point, and reflecting on other related developments, we found that the various models align on some architecture principles that promote interoperability across dimensions, yet still differ on other dimensions (e.g. data model and semantics, as well as how they address issues of identification, authentication and authorization). By taking the perspective of data space interoperability, we suggest that efforts towards developing meta-level agreements and standardization for the cross-data space are needed to enable data space interoperability.

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