Circular TwAIn

AI Platform for Integrated Sustainable and Circular Manufacturing

Deliverable

D4.3 Data Integration and Validation Report – 1st version

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Definitions and acronyms

AAS	*Asset Administration Shell*
AI	*Artificial Intelligence*
CA	*Certificate Authorities*
CDS	*Circular Data Space*
CE	*Circular Economy*
CEAP	*Circular Economy Action Plan*
CSR	*Certificate Signing Requests*
CTDA	*Circular Twain Data Agent*
DAPS	*Dynamic Attribute Provisioning Service*
DAT	*Dynamic Attribute Tokens*
DME	*Dimethyl Ether*
DoA	*Description of Action*
DPP	*Digital Product Passport*
DS	*Data Space*
DT	*Digital Twin*
EC	*European Commission*
EDC	*Eclipse Dataspace Components*
EO	*Ethylene Oxide*
EoL	*End of Life*
EU	*European Union*
GA	*Grant Agreement*
HSM	*Hardware Security Modules*
IAM	*Identity and Access Management*
IDP	*Industrial Data Platform*
IDS	*International Data Space*
IDSA	*International Data Space Association*
JSON	*JavaScript Object Notation*
KPI	*Key Performance Indicator*
OPC UA	*Open Platform Communications Unified Architecture*
PPE	*Personal Protection Equipment*
PC	*Project Coordinator*
TC	*Technical Coordinator*
THB	*Trial Handbook*
TPM	*Trusted Platform Module*
UC	*Use Case*
WEEE	*Waste of Electronic and Electrical Equipment*
WP	*Work Package*
XML	*eXtensible Markup Language*

Disclaimer

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Executive Summary

In Circular TwAIn, WP4 is devoted to the development of the infrastructure to support data acquisition, transformation, sharing, and processing, enabling Pilots' circular scenarios.

The present deliverable is reporting on the activities undertaken in the context of T4.5 (namely called "T4.5 *Data Integration, Testing and Technical Validation*"), hence it is aimed to verify the adherence of the proposed technologies and tools adopted or developed to the requirements collected on data for the circular value chain and to validate other WP4 tasks outcomes with respect to Pilots expectations.

The first issue to be solved was the absence of a reference standard methodology to be applied in the task; for this reason a **Verification and Validation Methodology** has been created starting from the approach proposed in AI REGIO [1] due to common AI technologies and partners involved, and it will be pursued for the whole task duration (i.e., also the activities to be carried on during the second phase of the Project have been detailed). The rationale behind such methodology is the need to assess in a holistic way the goodness of the requirements collected, and the technical dimension considering the Pilots needs and constraints.

A mapping exercise (core topic of Section 5) was deemed necessary to fulfil the scope, and it is considered to be a pivotal outcome also to support and inspire other WPs' activities: some further data sharing scenarios are suggested to Pilots, and may lead to the exploration of new business opportunities, within or outside Circular TwAIn, thus contributing also to the market analysis and exploitation activities. Meanwhile the blueprint proposed for each Pilot in Section 5 should be considered by technical partners for the whole development and mostly integration and deployment phases to constitute a common, validated source of knowledge: the circular manufacturing experimentation will be at the centre of the second period of the Project and it will represent its main outcome, resulting in the appropriate and functioning concretization of Pilots' commitment in sustainable manufacturing.

Finally, the structure of this document and, with some adaptations, the methodology defined and followed here, has been practiced also in the D4.3 twin deliverable (D5.3 "*System Integration and Validation Report - 1st version*"). In fact, in the other Circular TwAIn's WP dedicated to technical developments (i.e., WP5, focused on the development of AI-enabled Digital Twins) there is a parallel task on "*System Integration, Testing and Technical Validation*" (i.e., T5.6).

1 Introduction

1.1 Purpose and Scope

This deliverable D4.3 "*Data Integration and Validation Report – 1st version*" is aimed to report the results of the technical verification and validation of the Circular TwAIn WP4 outcomes.

In this first version the focus is on the verification of the applicability of the technologies selected (to be developed or adopted) to Pilots' UCs. Accent will be given also to possible scenarios opened by such technologies, given as suggestion to Pilots' or as suitable future applications enabled by Circular TwAIn.

The second version of the deliverable, expected at M36, will include the final validation (i.e., proved by the actual execution of Pilots' UCs) of the technologies in scope for WP4.

1.2 Structure of the document

Apart from the Introduction and the Conclusion and Future Outlook, the document is structured as follows:

- Section 2 defines the Methodology adopted to execute the validation of the Circular TwAIn's WP4 outcomes: the first phase of the methodology has been followed for the 1st version of the validation, while the second phase will be the subject of the 2nd and final validation;
- Section 3 reports the requirements relevant to WP4 to enable the data sharing scenarios, grouping them in 5 categories: data requirements, Data Space technical requirements, Data Space Business requirements, Technical requirements for Circular Economy (CE) and Business requirements for Circular Economy;
- Section 4 lists the technologies developed and adopted in WP4, considering the outputs of the four development tasks of WP4 (i.e., from T4.1 to T4.4);
- Section 5 maps the requirements identified and the technologies proposed to Pilots' domains, providing insights on the actual (M18) deployment expectation.

2 Verification and Validation Methodology

The key objective of Task 4.5 is to undertake the verification and validation of the outcomes from Circular TwAIn's WP4. This involves scrutinizing selected components of the Data Space and developed technologies to ensure their compliance with the established Project requirements. In D2.2 ("*User Scenarios, Requirements and Performance Indicators - 1st version*"), various requirements were identified pertaining to challenges and enhancements within the realm of a Circular Data Space (CDS). These fundamental requirements are subsequently contextualized within each Pilot, as outlined in the Project Trial Handbooks[1] and other deliverables, such as the deliverable D4.2 ("*Data Space Implementations for Materials/Products and Process/Production - 1st version*"). However, there is a lack of direct correlation between the WP4 outcomes and the overarching requirements, both general and Pilot-specific, that they are anticipated to fulfil.

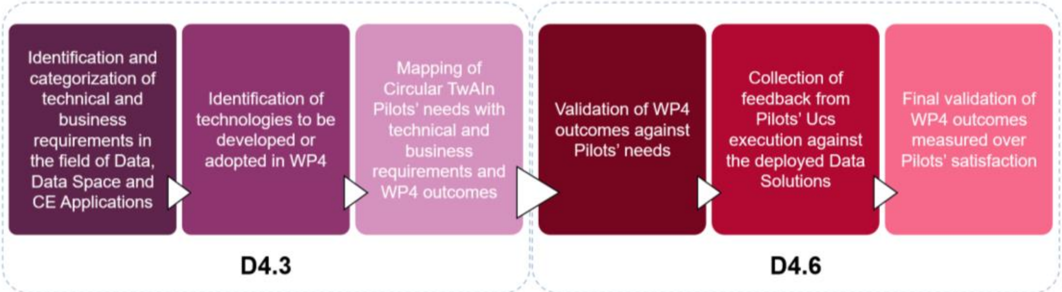

Figure 1: Verification and Validation methodology

Figure 1 provides an overview of the methodology adopted to verify and validate the outputs of Circular TwAIn's WP4. The proposed methodology has been adapted to Circular TwAIn's needs, features and timeline starting from the validation methodology defined in AI REGIO [1]: it unfolds in six steps organized into two phases, the first one more oriented towards the verification (i.e., the assessment the final WP4 results are in line with the Pilots' requirements), the second towards the validation (i.e., on the assessment the results are satisfying the operational needs).

The initial phase (left side of Figure 1) encompasses a preliminary verification of the technologies developed or adopted in WP4 based on the requirements identified in other WPs (mostly in WP2 and reported in D2.2) and follows with their validation with respect to the tools needed to enable Pilots' UCs execution. The second phase (right side of Figure 1) will be carried out during the second period of the Project (M19-M36) and it will include the final validation of the assets developed under WP4 with respect to Pilots' feedback. Its take aways will be reported in D4.6 "*Data Integration and Validation Report – 2nd version*" (due at M36).

The first step of this initial phase involves mapping requirements related to Data Space Components, Data Ontologies and all the technologies involved in this work package. This process aims to segregate, where feasible, the pertinent technical and business requirements, aggregating them into macro-categories. These macro-categories cover both

[1] The Trial Handbook is a confidential "living" document and the central information source for all tasks regarding the pilots, defining in detail the entire process carried out throughout the experiment and the outcomes and results of the activities performed.

technical and business requirements in three application domains: Data, Data Spaces, and Circular Economy, resulting in five distinct blocks: Data Requirements, Data Space Technical Requirements, Data Space Business Requirements, Technical Requirements for Circularity, Business Requirements for Circularity. The activities performed are reported in Section 3.

The second step, detailed in Section 4, focuses on the identification of the set of technologies to be developed or adopted in WP4 for constructing and support the Data Space adoption, (such as the Industrial Data Platform), as well as chosen data ontologies and semantics for use. All these components undergo detailed description and validation against the aforementioned requirements, ensuring their suitability to address the identified needs in terms of data, Data Space, and circularity.

The third and final step (reported in Section 5) of the initial phase consists in a preliminary Pilot validation: for each Pilot, a subset of requirements has been chosen in relationship with the needs in Project documentation.

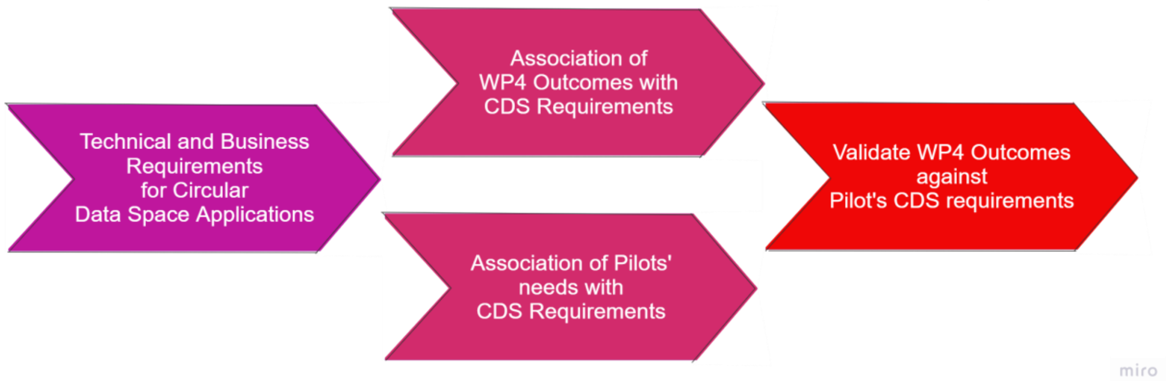

Figure 2: Detail of the Verification and Validation Tasks on the first phase

The second phase will involve the selection of suitable WP4 outcomes able to cover Pilots' needs, the validation of the selected architecture for each Pilot (i.e., deployment and integration) including insights on the iteration needed to achieve the desiderata, thanks to their feedback. Further details will be expounded upon in Deliverable 4.6, representing the second iteration of the current document.

3 Technical, Business and Circularity Requirements for Data, Data Space and Circular Applications

In this section the requirements identified in WP2 and reported in D2.2 ("*User Scenarios, Requirements and Performance Indicators - 1st version*"), especially the ones related with the objectives of WP4 (i.e., data, Data Spaces) and the application domain (i.e., Circularity), have been further analysed and better described highlighting the technology context. Furthermore, in the timeframe between the D2.2 submission in (M9) and the time this deliverable is written (M18), some extra requirements have been identified and reported here.

3.1 Data Requirements

Data requirements encompass a series of features that data must exhibit in the context of a Circular Data Space (CDS). In the context of a CDS, understanding and defining data requirements become crucial for effective information management. A CDS implies a continuous and interconnected flow of information so that the implementation of data circularity can reflect to their sources. To meet the requirements of such a dynamic environment, it is essential to identify the specific data elements, their relationships, and the necessary quality standards. This involves recognizing the inputs and outputs within the circular data flow, establishing protocols for data capture and storage, and ensuring compatibility for smooth integration.

The following requirements list summarizes the information collected in D2.2 and extends them with some common needs related to the technologies that will be mentioned in the Section 4 of this document:

- **Data Quantity:** Quantity is a critical data requirement in the context of a CDS as it determines the volume of information flowing within the system. The continuous circular nature of the Data Space implies a dynamic and ongoing exchange of data points. Being able to envisage and manage the quantity of data generated, processed, stored and recycled is essential for maintaining system efficiency and preventing data overload. It allows for the optimization of infrastructural resources but also impacts the gathering of insights through data-driven prediction systems, ensuring the seamless flow of data within the circular framework.
- **Data Quality:** Quality is a fundamental feature that data must exhibit. High-quality data for circular economy should be intrinsically good, contextually appropriate for circularity of data needs, clearly represented and accessible to the data consumer. There is a positive correlation between optimal data quality and maximising the economic value of data, especially when the aim is to exploit this data in the long term through data recycling.
- **Data Confidentiality:** Confidentiality refers to the property of certain sensitive information to be protected from unauthorised access or disclosure. It ensures that only authorized individuals or entities have access to certain data, preventing unauthorized parties from viewing, altering, or distributing the information. Data confidentiality is vital for safeguarding sensitive information, protecting privacy, and ensuring legal compliance. Confidentiality requirements for a Data Space involve the

implementation of measures to safeguard sensitive information and restrict access to authorized entities.

- **Data Portability:** Portability refers to the ability of individuals or organizations to move and transfer their data seamlessly between different systems, platforms, or services. It ensures that users can easily access, share, or migrate their personal or business data across various applications, devices, or environments while maintaining its integrity and usability. In a circular context, data crosses different stages in the product lifecycle, therefore with the possibility of involving several systems in the process. Data portability ensures all systems to be able to preserve data structure and integrity, enabling data circularity.
- **Data Standardization:** Standardization is a property of data that involves establishing and adhering to a consistent format, structure, and representation for information. It ensures uniformity in the way data is collected, stored, processed, and exchanged within a system or across different systems. Standardizing data includes defining common data formats, units of measurement, coding conventions, and other specifications, making it easier to integrate and analyse information. In a circular economy, where resources are reused, recycled, and repurposed, standardized data ensures consistency in reporting, tracking, and sharing information about product lifecycles, materials, and environmental impact.
- **Data Interconnectedness:** Interconnectedness refers to the data property of being linked together and able to exchange information between various datasets, systems, or devices. In a highly interconnected data environment, different components, platforms, or sources are integrated to enable efficient communication and data flow. This property ensures different stakeholders, such as manufacturers, suppliers, consumers, and recyclers to exploit data for their needs.
- **Data Recycling:** Recycling is a property that involves the systematic reuse and repurposing of data throughout its lifecycle. Like the principles of material recycling in a circular economy, data recycling emphasizes extracting enduring value from existing datasets. This practice contributes to sustainability efforts by minimizing data redundancy and waste. In a Data Space within a circular economy framework, efficient data recycling enables stakeholders to derive insights from previously collected information for a more resource-conscious approach to data management.

3.2 Data Space Technical Requirements

Data Space technical requirements for circularity go beyond traditional considerations, incorporating elements that support sustainable and circular practices. Whereas interoperability is a crucial requirement for each Data Space, in a circular economy context the transparent tracking of materials and a seamless collaboration among stakeholders must be considered. This is achievable through data adherence to standardized formats which should contain information about environmental impacts of products, processes and materials. Implementation of data recycling capabilities become crucial, allowing for the repurposing of data to optimize resource usage and inform circular strategies.

- **Connectivity:** From a functional standpoint, ensuring connectivity is fundamental for a Data Space because it supports essential aspects like trust, security and data sovereignty. The concept goes beyond the basic communication, playing a vital role in facilitating partnerships, creating value, and enabling cross-domain data services in an iterative manner. The seamless interaction between various components within a Data Space is really important, ensuring a cohesive and collaborative environment for participants.

- **Data Filtering and Aggregation:** Data Space Architecture commonly relies on isolation as a key design principle to ensure the effective implementation of data sovereignty functionalities. Within this framework, the data filtering and aggregation application concept plays a crucial role in facilitating data storage, access, and processing. The goal is to prioritize the privacy of sensitive data by conducting processing near the data source. Backend services or applications are responsible for any necessary data pre-processing, such as filtering, anonymization, aggregation, or analysis. Connectors, on the other hand, should exclusively provide data that is intended to be shared with other participants in the system. This approach ensures a secure and controlled flow of information within the Data Space.
- **Data Storage:** A distinctive feature of Data Spaces is the prioritization of decentralization in data storage. The fundamental principle is that data remains with the owner until it is transferred to a trusted party. This strategy necessitates a comprehensive understanding of each data source, coupled with a clear assessment of the value and usability of data for other entities. The integration of domain-specific data vocabularies becomes crucial in creating a harmonized and standardized approach to diverse datasets.
- **Data Transaction:** In the context of a Data Space, the concept of data transaction revolves around ensuring a trusted exchange of information among participants. This involves verifying the identities of participants and confirming their compliance with defined rules and agreements. Achieving this assurance can be approached through a combination of organizational measures, such as certification or verified credentials, and technical measures like remote attestation. The focus is on creating a secure and transparent data exchange environment that fosters confidence among participants.
- **Decision Support or Actuation:** The digitalization of the manufacturing sector hinges on leveraging data sharing and exchange to accomplish objectives that would be otherwise unattainable. At its core, this digitalization process involves capturing data at a granular level, followed by advanced data analysis, the implementation of decision support systems, and the capability to directly actuate events in the real environment. This streamlined and technologically advanced approach is integral to enhancing efficiency, optimizing processes, and adapting to dynamic manufacturing requirements.
- **Data Treatment:** Data treatment, distinct from traditional data processing, centres around managing data "as expected" to yield anticipated results. In the context of a Data Space, specialized Data Space Applications offer a dedicated set of tools designed to treat information to be exchanged. This ensures that the data is handled in a manner aligned with predefined expectations, maintaining consistency and reliability in the interpretation and utilization of exchanged information. The focus is on enhancing the utility and reliability of data within the Data Space ecosystem.

3.3 Data Space Business Requirements

Data Space business requirements involve a holistic approach to ensure the seamless functioning of a collaborative data-sharing environment. These requirements typically include a legal framework for data governance, ensuring responsible and compliant data management.

- **Data Monetization:** Data Spaces must establish a framework for defining and enforcing agreements on data usage, encompassing potential monetization of both data provision and utilization. This involves allowing capabilities for specifying and publishing data offerings, including terms and conditions (such as pricing) that can be enforced during data exchange transactions.
- **Data Business Model:** In a Data Space, participants, including those providing or consuming data and software vendors, can implement their own solutions. The creation and ongoing maintenance of this set of agreements form a business model focused on collective funding for Data Spaces, without a profit objective. The funding's viability is tied to the adoption rate of European Data Spaces and their significance for participants.
- **Data Sovereignty**: Data Sovereignty's primary focus is to allow individuals or organizations to autonomously determine their data. Stakeholders gain control over their data by making decisions on how digital processes, infrastructures, and data flows are structured, built and managed. This is guided by an appropriate governance scheme that specifies terms and conditions.
- **Data Discovery**: Data discovery encompasses the activities involved in locating and categorizing data to render it valuable for specific purposes. Organizations undertake data discovery for diverse reasons, frequently aiming to unveil patterns, address business challenges, and shape strategic initiatives. Within the realm of data privacy compliance, data discovery takes on a distinct meaning, referring to the process of pinpointing data that necessitates management to adhere to compliance requirements. This may involve identifying systems that gather personal information to address opt-out requests, determining destinations where data is shared with external entities, or locating personal information of data subjects to facilitate responses to subject rights requests.
- **Trustworthiness:** A trustworthy data ecosystem should be able to overcome obstacles opposing to the proper use of data. These obstacles include diverse treatments, insufficient data compatibility and interoperability, a shortage of data-related skills and digital literacy, and a lack of trust in data sharing. Ensuring the benefits of data-driven services necessitates making a broader range of data available for reuse.

3.4 Technical Requirements for Circular Economy

This block of requirements encloses all the technical aspects necessary to ensure Circular Economy principles are considered in the context of Circular TwAIn.

- **Material Traceability:** It is a key requirement for circularity, and it comprehends all the technical aspects that may involve the history of materials composing a product.

It starts with a technical way to ensure material origin, as well as the path they took during the creation, usage and disposal of a product. This ensures the material flow to be tracked since its first use in industry, so that material can be re-used and tracked for a second life.

- **Information Traceability:** Information traceability covers a principal role in tracking material, product and waste flows along the value chain, as well as is useful to identify possible opportunities for waste reduction or material re-utilization. Information traceability technical aspects open new ways to build new circular business model and to improve resource usage.
- **Information and Material Sharing:** Building an infrastructure that allows the sharing of previously tracked material data and information among the stakeholders of a product value chain is mandatory to create a closed loop material flow.

3.5 Business Requirements for Circular Economy

Circular Economy aspects fall into two main business objectives:

- **Closed-loop material flow:** It involves different stages of the production process, from the recovery of waste at the end-of-life stage of the product value chain, enabling the reuse of materials and/or product parts, to the recovery of production materials to be reintroduced into the production line. This allows a lower usage of virgin material and, as an environmental impact, to reduce waste production.
- **Waste Reduction:** Waste reduction is a collateral requirement coming from circularity models that helps minimizing ecological impact of industries. Reducing the environmental impact is essential and is economically profitable and if attained through efficient material utilization, minimization of production scraps, a decreased material consumption and by promoting the reuse and recovery of post-use materials.

4 Identification of the technologies developed or adopted in WP4

Hereinafter, the technologies developed or adopted in WP4 and extensively discussed in other WP4 deliverables (i.e., "D4.1 - *Circular TwAIn Industrial Data Platform, Standards Ontologies - 1st version*", and "D4.2 - *Data Space Implementations for Materials/Products and Process/Production - 1st version*") are listed to make this document self-standing. The descriptions associated have been revised with respect of previous deliverables to focus only on the technological landscape (main functionalities of the technologies) and the enabled features (i.e., the possible applications) without reporting the whole technical specifications of such components/technologies.

4.1 Industrial Data Platform

The Industrial Data Platform (IDP) is a technology infrastructure based on the Circular TwAIn Reference Architecture and designed in this project like a toolset of components can be enabled on demand to cover the needs of the users want to adopt it. Its purpose is to enable the ingestion of data generated within an industrial environment, process and transform them with the objective to feed the brokering layer. In this way the data can be consumed for analysis purposes.

The IDP can serve as an optional intra-company toolset for managing and integrating data from heterogeneous sources, such as sensors, machines, devices, and production systems, ensuring data to adhere to defined models. It is designed to be deployed at the ends of the industrial Data Space network to act as a Man-in-the-Middle between Digital Twins and the Data Space itself, but due to its flexibility there are no specific constraints in case of different types of deployment. Going into detail about Industrial Data Platform functionalities there is the *Data Ingestion and Brokering* to receive data from existing entities, such as physical products, processes, humans and/or their Digital Twin representation, enabling a bi-directional communication with them. The Platform is also able to integrate in a flexible way with other systems such as NOVAAS [2] or FA³ST [3], i.e., the brokering components in charge to provide both the state of Digital Twin and the results coming from the processing layer. The *Data Processing* consists in transforming and mapping techniques applied to data, allowing users to work on heterogeneous data sources while adhering to data models. This layer also enables cognition in Digital Twins, enabling batch and real-time processing on their data. The *Data Persistence*, whenever necessary, allows to historicize data, especially when time-series data are involved in fast-changing entities. Finally, the Data Models and Vocabularies provided by FIWARE Smart Data Models [4] initiative facilitate seamless communication within an Industrial Data Space environment.

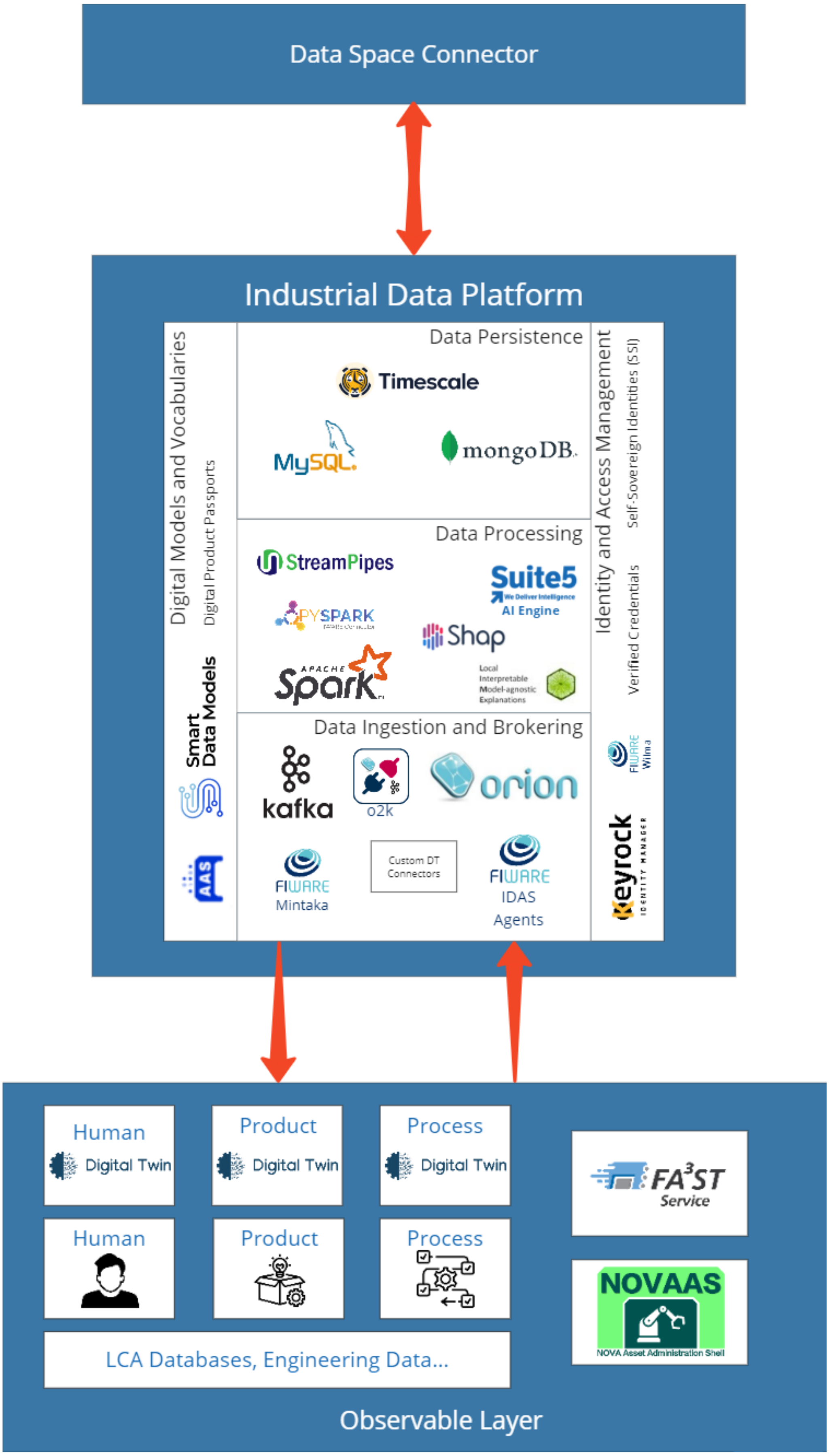

Figure 3: Industrial Data Platform

So that the main objective of the IDP is the Brownfield Integration, facilitating the enabling of existing digital twins with new technologies. This is guaranteed thanks to its flexibility, ensuring the integration of already existing implementations without changing them. At the same time the data ingested from heterogeneous data sources are harmonised and could be enabled the cognition supporting batch and real-time data processing. Once the data are ready, they are put at the disposal of a Data Space in order to share them.

4.2 Data Space

The Data Space (DS) satisfies the IDS standard enabling trustworthy data exchange among certified data providers and recipients, based on mutually agreed rules. Data Spaces improve cooperation, lower the barriers to entry and enhance innovation. The next subsections are aimed to shed light on the IDS Data Space components as per Figure 4.

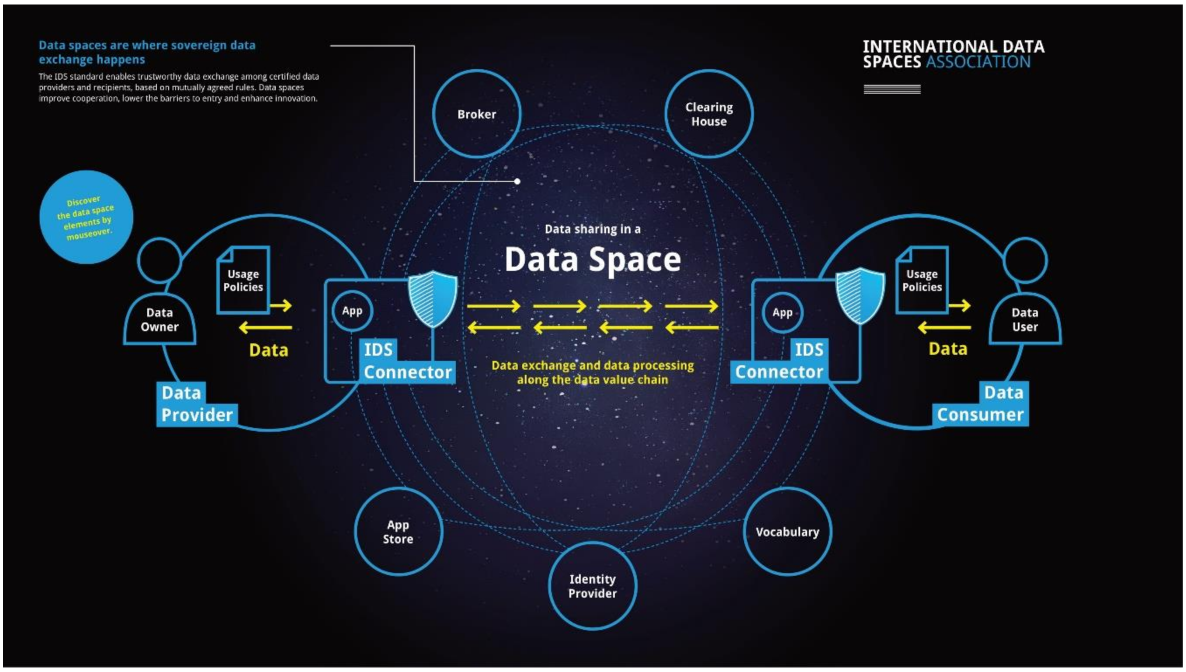

Figure 4: IDSA Data Space [5]

4.2.1 IDS Connectors

The IDS Connector plays a crucial role in a Data Space. It is a dedicated software component that allows participants to attach usage policies to their data in a Data Space, enforces the usage policies and seamlessly tracks data provenance. The Connector acts as a gateway for data and services and as a trusted environment for apps and software. Among the IDS connectors the two selected components since they have different features can cover a several needs with the aim of developing a Data Space (and especially the latter, but also the former, has already multiple derivative works to provide customized versions of alternative connectors):

- **TRUE Connector [6]:** it enables the trusted data exchange in order to be active part of an IDS Ecosystem, a virtual Data Space leveraging existing standards and technologies, as well as governance models well-accepted in the data economy, to facilitate secure and standardized data exchange and data linkage in a trusted business ecosystem. The connector is compliant with the latest IDS specifications and can be easily customized to fit a wide spread of scenarios thanks to the internal separation of Execution Core

Container and Data App. It is integrable with a lot of existing IDS services and totally configurable in terms of internal/external data format (multipart/mixed, multipart/form, http-header) and protocols (HTTP, HTTPS, Web Socket over HTTPS, IDSCPv2).

- **Eclipse Dataspace Connector:** The Eclipse Dataspace Components (EDC) [7] is a comprehensive framework (concept, architecture, code, samples) providing a basic set of features (functional and non-functional) that Data Space implementations can re-use and customize by leveraging the framework's defined APIs and ensure interoperability by design. It is powered by the specifications of the Gaia-X AISBL Trust Framework [8] and the IDSA Dataspace protocol. The EDC is designed for developers who want to build Data Space implementations on an existing, standards-based framework and adopt and adapt it with their own solutions: developers use the EDC to build data-sharing services for their customers. The framework consists of a set of components and corresponding capabilities that are mandatory to implement a dataspace: Connector, Federated Catalogue, Identity Hub, Registration Service, Data Dashboard (Management UI).

4.2.2 Identity Provider

To be able to make access control related decisions that are based on reliable identities and properties of participants, the introduction of the concept for Identity and Access Management (IAM) is mandatory. To access resources in the IDS, aspects of identification, authentication, and authorization need to be defined. The Identity Provider in the IDS consists of three complementary components: Certificate Authorities (CAs) are responsible for issue and manage technical identity claims, the Dynamic Attribute Provisioning Service (DAPS) provides short-lived tokens with up-to-date information about connectors. A DAPS enriches connector identities by issuing up-to-date information in form of signed claims. It embeds them into Dynamic Attribute Tokens (DATs) which are handed out to requesting IDS Connector instances. The DAPS verifies the current status/validity of Software Manifests and Company Descriptions which contain metadata regarding passed IDS certifications. Simultaneously it delivers dynamic attributes, such as device location or currently supported transport certificates, which may dynamically change over time and are linked to the connector identity based on the DAT. Thus, a DAPS is used to provide dynamic, up-to-date attribute information about Participants and Connectors. Using a service to hand out attributes in a dynamic fashion reduces the need for certificate revocation and enables more flexible attribute handling for participants in the International Data Spaces.

4.2.3 Certification Authority

One or multiple CAs issue identity certificates for connector instances by signing Certificate Signing Requests (CSRs) that have been handed in by valid connector instances. They revoke certificates that become invalid and, for higher trust levels, assure that private keys are properly stored in hardware modules (such as a TPM or HSM [9]). They are essential trust building entities responsible for ensuring that only registered organizations may operate components in the IDS.

4.2.4 IDS Metadata Broker

The IDS Metadata Broker is an IDS Connector, which contains an endpoint for the registration, publication, maintenance, and query of Self-Descriptions. A Self-Description encapsulates information about IDS Connector itself and its capabilities and characteristics. This Self-Description contains information about the offered interfaces, the owner of the component and the metadata of the data offered by the component. A Self-Description is provided by the operator of the Connector. The Self-Description in total can be seen as metadata. An IDS Connector providing a service or data can send its Self-Description to a IDS Metadata Broker so that every participant is able to find it within the Data Space. The IDS Metadata Broker can be understood as a phone book. Within a Data Space, there can be multiple IDS Metadata Brokers allowing to distribute the IDS Metadata Broker functionality. It is up to the Data Space authority to decide if there is a leading IDS Metadata Broker or if the different instances operate independently. An IDS Metadata Broker may provide additional services that in term must be described by using terms from the IDS Information Model in the respective Metadata Broker's Self-Description document.

4.2.5 Digital Clearing House

The IDS Clearing House consists of an IDS Connector and bases all its functions on a logging service that records information relevant for clearing and billing as well as usage control. The Clearing House uses this information to provide a Clearing and Settlement Service based on usage contracts and helps with the atomization of payments between Data Provider and Data Consumer. It can also use this information to provide a Billing Service to allow the Data Space Operator the billing of the participants. The Usage Control Claim Validation service uses the logged usage control data to allow the validation of usage claims on resources.

4.2.6 Usage Control

Usage control is an extension to traditional access control. It is about the specification and enforcement of restrictions regulating what must happen to data. Thus, usage control is concerned with requirements that pertain to data processing, rather than data access. Usage control is relevant in the context of intellectual property protection, compliance with regulations, and digital rights management. Therefore, the purpose of usage control is to bind policies to data being exchanged and to continuously control the way how messages may be processed, aggregated, or forwarded to other endpoints. This data-centric perspective allows the user to continuously control data flows, rather than accesses to services. At configuration time, these policies support developers and administrators in setting up correct data flows.

4.2.7 Data Vocabulary

The interoperability is enabled by the adoption of commonly known, standardized terms to describe data, services, contracts, and so on. The collection of these standardized identifiers forms the so-called vocabularies. In the most basic appearance, any list of controlled terms can be a vocabulary. To make use of their content, the respective vocabulary documents need to be shared between the relevant parties. This can be done through digital catalogues but also in printed forms like for instance a language dictionary. The terms of the vocabulary must be machine-readable, also to some degree their descriptions and titles, as well as new terms must be available for lookups. In specific domains, however, more and more expressive terms are needed. It is therefore a good practice to extend the basic information model with additional vocabularies and provide them in the same ways as the core one. To do so, a certain service is needed to provide a platform to host, maintain, publish, and document the additional vocabularies. This service is the Vocabulary Provider. It provides endpoints to enable the seamless communication with connectors and infrastructure components. Vocabulary Provider give access to the defined terms and their descriptions, present changes and outline the different versions.

4.3 Asset Administration Shell

The Asset Administration Shell (AAS) is the standardized digital representation of an asset, the corner stone for the interoperability of Industry 4.0 components organized in Industry 4.0 systems. The AAS may be the logical representation of a simple component, a machine or a plant at any level of the equipment hierarchy. The manufacturer provides the standardized digital representation to his customers, creating both an AAS for the asset type and for each asset instance. The system designers, the asset users, the applications, the processes and the asset itself update the information of the AAS during the lifetime of the asset until its disposal. From the manufacturer's point of view the asset is a product. The manufacturer manages different asset types that have a history with different versions. In parallel, he produces instances of these different types and versions. The structure of the AAS is defined via a technology independent metamodel and several technology specific serialization mappings such as XML, JSON or OPC UA. Its contents are defined via domain-specific submodel templates. The interaction with the AAS can follow different patterns which have different technical requirements, i.e., file exchange, server-client and peer-to-peer interaction.

4.4 Digital Product Passport

Digital Product Passport (DPP) goal is to gather data on a product and its supply chain and share it across entire value chains to all actors, including consumers. The idea is to obtain a better understanding of the materials and products used and their embodied environmental impact. The DPPs initiative is part of the proposed Eco-design for Sustainable Products Regulation [10] and one of the key actions under the Circular Economy Action Plan (CEAP) [11]. The implementation of DPPs in a value chain is designed to support a sustainable product production, enabling the transition to Circular Economy and therefore boosts material and energy efficiency, extends product lifetimes, and optimizes product use. Then to create value through Circular Business Models, thanks to the improved access to data with Digital Product Passports more businesses can implement service and repair-based business models. The consumers to make more informed purchasing decisions once they are provided with information on the total impact of their buying behaviours. At the end verify compliance with legal obligations: the Digital Product Passports will also act as a record of the standards a product complies with and provides auditors with the data to evaluate this.

4.5 DT Registry

DT Registry is a centralized or decentralized repository that stores and manages Digital Twin (DT) models and instances within the Circular Economy Data Space. It provides a repository for DT descriptions, enabling stakeholders implementing Circular Twain Data Agent (CTDA) to access and interact with DTs of products, materials, processes, and production systems.

5 Mapping of Circular TwAIn Pilots' needs with Technical and Business requirements and WP4 outcomes

The requirements reported in Section 3 are applicable in case of Data Space adoption and Circular Applications development. The next step is to contextualise them from the perspective of the Pilots' needs; hence it is necessary to gather information by conducting a deep study of each use case aims, encountered challenges to be overcame and risks to be avoided. The intermediate step consists in individuating a set of main requirements that best fits with the preliminary analysis conducted on Pilots, with the future aim of selecting the right technologies to fulfil them, i.e., the (sub)set of components and models to be actually deployed for each Pilot for the execution of the scenarios (this aspect will be discussed in the second phase). Outcomes are not one-to-one mappings with requirements, but a first selection that will be refined during the second iteration where the deployed solution will be finally validated.

From a first analysis, Pilots can be distinguished into two categories:

- **Product-Driven Industry** where the focus on circularity is put on products and their use cases are based on the treatment, disassembly and recycling of products, parts and material; in this category it is possible to identify WEEE and BATTERY Pilots.
- **Process-Driven Industry** where the focus on circularity shifts to processes and the use cases are related on process optimization and process waste management and re-utilization; in this category it is possible to identify the PETROCHEMICAL Pilot.

The next subsections present the main results of this document reported in tabular form, namely the mapping between the requirements elicited in Section 3, the enabling technologies as identified in Section 4 and the UCs defined so far by Pilots in THB and discussed during dedicated meetings and General Assemblies. Some rows in the tables reported in the next subsections are highlighted in green to show that are relevant requirements to the pilots. It means that the selected requirements are connected the technologies candidates to cover the needs of the UCs.

Finally, it is worth to remark that for each 'requirement vs identified technologies' the domain specific applicability is given by concrete examples, in some cases going beyond the borders of the Project with the intent to suggest further scenarios in and out of Circular TwAIn.

5.1 WEEE Pilot

The WEEE Pilot is doing a significant effort to improve the handling of electronic waste, particularly of desktop computers. The aim of this Pilot is to create a circular process where these computers are either refurbished for a second life or disassembled to retrieve reusable spare parts. Goals include increasing the value get from recycled components by 20%, automating over 25% of disassembly tasks, and cutting the time it takes to break down IT equipment by 30%. Technologies like artificial intelligence and collaborative robotics are used to make these processes more efficient. The Pilot covers various areas, from using computer vision to break down equipment to creating a decision support system based on market needs. The main objective is to set new standards for sustainable electronic waste management in Europe, ensuring economic benefits while being environmentally responsible.

5.1.1 Requirements vs identified technologies

From the WP4 perspective, the following requirements are gathered from the use cases:

- **Data Quantity:** the use cases gather data from several data sources, from product RGB images, CAD files, point clouds, PC specifications, market data to even process specification. Quantity refers both to the amount of data gathered and to the weight of files that are exchanged.
- **Data Quality:** data quality is a mandatory and fundamental requirement to produce valid AI predictions. Since the use cases strongly require the use of AI (i.e., image recognition, part recognition…), data quality is a requirement that must be kept under consideration.
- **Data Portability:** The need to access external systems to retrieve data, for example from commercial partners datasets (i.e., the equipment manufacturer, such as Lenovo, HP, Dell etc.), require that data is provided in highly portable formats.
- **Data Standardization:** in WEEE Pilot, standardization is applicable to both products and processes. In the first case, Digital Twin of products requires a standardized structure to cover the aforementioned data requirements. On the other hand, even dismantling processes may be provided with standardized formats and languages, so that best practices may be gathered and shared in the planning domain world. To structure a scenario that covers many stakeholders of the Circular Value Chain, such requirement is mandatory and its actual elicitation towards a data model creation has to be agreed by the parties.
- **Data Interconnectedness:** The development of WEEE products Digital Twins by leveraging heterogeneous sources of data requires those sources to be highly interconnected so that their data can be integrated into high-quality, reliable and consistent datasets ready to be used in AI applications.
- **Data Recycling:** The main purpose of the Pilot is to try giving a second life to electronical wastes where the subparts of a product are evaluated to be reusable. Data gathered during this evaluation phase can then be recycled to (i) be included in the next ‘product’ associated with such subpart, (ii) feed further analysis to improve the subpart validation itself. Further, the data gathered in each step of the Circular Value Chain may be useful to reflect on possible improvements in the whole process: for instance, data associated with the disassembly process may be relevant to support the accountable of the design of the product to enhance the overall assembly and disassembly processes.
- **Connectivity:** The presence in the Project of at least two stakeholders of the WEEE Circular Value Chain may lead to the need of building a Data Space for several sources of data, like PC specs, PC market data and material market data. Ensuring connectivity to a Data Space sharing this kind of information can allow the various stakeholders of the Pilot to gain access to new sources of data and apply corrective strategies where needed (as per the example of the previous bullet). The need of a

Data Space is even more relevant thinking on a wider scenario, where all the stakeholders of the Circular Value Chain are cooperating to optimize and enhance the whole process.

- **Decision Support or Actuation:** The intensive use of AI and Digital Twins in the Pilot requires the bidirectional communication between the digital and physical worlds, especially in robotic collaborations.
- **Data Transaction:** The Pilot expressed the need for exchange data with partners in the business, meaning that the data exchange procedures must be regulated with a data governance framework. The Data Space and its native data sovereignty principle is the designed enabler technology to meet this requirement in Circular TwAIn.
- **Data Treatment:** To allow the exploitation of data for AI applications, data must be ensured to follow standards for the Data Space. Data treatment tools may be useful to shape data from external services into expected structures and standards whenever data are not provided in such forms.
- **Data Discovery:** The need of gathering essential data for some applications (such as use case E where product and material economic data are lacking[2]) raises the requirement of data discovery components to mitigate the risk of data absence. Such component may be also involved in other UCs to increase the informative base for the AI toolkit.
- **Trustworthiness:** From the business perspective, one of the most important Pilot requirements is the need of well-structured ready-to-use data. Ensuring trustworthy data exchange within a Data Space can facilitate the use of gathered data, without the need of further treatment.
- **Information and Material Sharing:** In the WEEE Pilot, being able to access circular material and information flow plays a key role to cover the risk of lacking data, especially in the perspective of re-selling components extracted through the de/re-manufacturing processes. The Digital Product Passport adoption would be a baseline to increase the knowledge on the product and its subcomponents even after the end of the first usage life.
- **Waste Reduction:** The purpose of the WEEE Pilot is mainly to increase the re-manufacturing of electronic wastes, hence the main circular business aspect is to reduce wastes.

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[2] *This information has been shared by the Pilot during a General Assembly and as far as the writer knows is not reported in any deliverable at the moment.*

Table 1: WEEE Pilot mapping over identified requirements and technologies

Requirements \ Data Space Components	Industrial Data Platform	TRUE Connector	Eclipse Dataspace Connector	Asset Administration Shell	Digital Product Passport	Identity Provider	Certification Authority	DT Registry	Data Vocabulary	IDS Metadata Broker	Digital Clearing House	Usage Control
Data Requirements												
Quantity	x											x
Quality	x			x					x			
Confidentiality	x	x	x			x	x					x
Portability	x	x	x	x	x			x	x			
Standardization	x			x	x			x	x	x		
Interconnectedness	x					x		x	x	x		
Recycling				x	x							
Data Space Technical Requirements												
Connectivity	x	x	x	x		x	x			x	x	
Data Filtering & Aggregation	x			x								
Data Storage	x							x				
Data Transaction	x	x	x			x	x				x	x
Decision Support or Actuation	x	x	x									
Data Treatment	x											x
Data Space Business Requirements												
Data Monetization												
Data Business Model				x					x			
Data Sovereignty	x	x	x			x	x				x	x
Data Discovery								x	x	x	x	
Trustworthyness	x	x	x	x	x	x	x				x	
Technical Requirements For Circularity												
Material Traceability					x							
Information Traceability					x						x	
Information and Material Sharing					x							
Business Requirements For Circularity												
Close Loop Material Flow				x								
Waste Reduction				x								

5.2 BATTERY Pilot

The Circular TwAIn BATTERY Pilot aims to enhance the efficiency of the current circular value chain for automotive battery systems, which currently lacks optimization in recovering functionalities and materials. The existing process involves batteries being transported to authorized dismantlers for disassembly, where battery modules or cells are subjected to recycling treatments. The Pilot introduces innovative circular economy nodes to this framework. End-of-life batteries are first assessed for reusability, and compliant batteries are directly reused in automotive or stationary applications. Batteries not suitable for direct reuse undergo disassembly and testing at the module and cell levels. Reusable units are then reassembled into second-life batteries, while those with no residual electric properties undergo recycling for raw material recovery. Key performance indicators include a 10% reduction in battery disassembly time, a 20% increase in disassembly automation, a 25% increase in the fraction of reusable batteries, a 15% reduction in testing time, and a 20% increase in profitability compared to standard recycling practices. This Pilot aims to optimize the entire value chain for automotive battery systems, promoting sustainability and circularity.

5.2.1 Requirements vs identified technologies

From the WP4 perspective, the following requirements were selected from aims, challenges and risks individuated in Pilots use cases:

- **Data Quantity:** Similarly to WEEE Pilot, also the BATTERY one relies on several heterogeneous sources of data, which implies CAD files (or parts of them), RGB images, cloud points, several time-series datasets, tabular data about battery state of health and performances, etc. These kinds of data are variable in both size and numerosity, hence being able to manage large amounts of data is fundamental for the Pilot success.
- **Data Quality:** The BATTERY Pilot heavily relies on artificial intelligence for lots of its use cases. Moreover, there are some disassembly steps that may be hazardous. For this reason, ensuring a high data quality is necessary for AI software to produce high quality results, especially in safety critical operations.
- **Data Confidentiality:** Full battery assembly CADs are often highly confidential data that are shared with a protected channel between a battery manufacturer and a carmaker. Being able to ensure confidentiality is essential to have access to such information.
- **Data Standardization:** Analysing Pilots’ use cases brought to the attention of the lack of standardization in several fields. For example, high variety of battery design brought to low standardization even in measurements of their performance or their state of health. Defining standards for participants in a Data Space to adhere to a well-defined product information structure is crucial to reduce variety and thus increase usability of data. Moreover, BATTERY Pilot aims to anticipate the European Regulation on batteries, the Digital Product Passport (DPP), that will be available in 2027 [12].

- **Data Recycling:** BATTERY Pilot aims giving second life to both batteries, packs, cells or even materials (especially rare earths). Being able to track material and product data, during their second lives allows a better understanding of the state of health of reborn products and enhances their recycling processes. Such understanding will be higher in the future when the DPP will become mandatory, and the R-Cycle actors will be able to access the history of the product and its subparts and materials from the beginning.
- **Data Filtering and Aggregation + Data Storage:** Local processing of data results necessary for a Pilot who needs to increase their data base. Since there is lots of variety, it may be necessary to use data cleaning, preprocessing and augmentation techniques, which needs data to be stored locally and being available.
- **Decision Support or Actuation:** The intensive use of AI and Digital Twins in the Pilot requires the bidirectional communication between the digital and physical world, especially in robotic collaborations.
- **Data Treatment:** To achieve the building of standardized data structures, such as DPPs, data treatment is a must-have requirement.
- **Data Discovery:** Building a Data Space where several businesses partners can join, helps the sharing of data, hence increasing the availability of the currently lacking sources. Being able to discovery sources based on own needs increase the success chances of Pilot aims.
- **Trustworthiness:** Due to the lack of available data source, guaranteeing reliable exchanges of data within the Data Space can enhance the utilization of collected data, eliminating the necessity for additional processing or refinement.
- **Material Traceability:** The European DPP main aim is to track and certify origin of products and their material. Since rare earths are precious material, having systems able to track their lifecycle is fundamental to pursue this aim.
- **Information Traceability:** Along with the material traceability, every information related to the battery (such as the state of health tracked in different stages or life of the product) may be useful to generate a virtuous cycle of improved AI applications able to assess a product usability.
- **Information and Material Sharing:** Lack of battery product and economic data is one of the biggest challenges of the Pilot. Being able to share them with partners can improve the circularity KPIs for every participant of the Data Space.
- **Close Loop Material Flow:** Rare earths are precious materials that may be recycled in other products, so that are whole battery cells. Being able to recycle materials bring to several business and environmental advantages.
- **Waste Reduction:** Exhausted batteries are extremely pollutant and being able to recycle them produces several environmental advantages.

Table 2: BATTERY Pilot mapping over identified requirements and technologies

Requirements \ Data Space Components	Industrial Data Platform	TRUE Connector	Eclipse Dataspace Connector	Asset Administration Shell	Digital Product Passport	Identity Provider	Certification Authority	DT Registry	Data Vocabulary	IDS Metadata Broker	Digital Clearing House	Usage Control
Data Requirements												
Quantity	x											x
Quality	x			x					x			
Confidentiality	x	x	x			x	x					x
Portability	x	x	x	x	x			x	x			
Standardization	x			x	x			x	x	x		
Interconnectedness	x					x		x	x	x		
Recycling				x	x							
Data Space Technical Requirements												
Connectivity	x	x	x	x		x	x			x	x	
Data Filtering & Aggregation	x			x								
Data Storage	x							x				
Data Transaction	x	x	x			x	x				x	x
Decision Support or Actuation	x	x	x									
Data Treatment	x											x
Data Space Business Requirements												
Data Monetization												
Data Business Model				x					x			
Data Sovereignty	x	x	x			x	x				x	x
Data Discovery								x	x	x	x	
Trustworthyness	x	x	x	x	x	x	x				x	
Technical Requirements For Circularity												
Material Traceability					x							
Information Traceability					x						x	
Information and Material Sharing					x							
Business Requirements For Circularity												
Close Loop Material Flow				x								
Waste Reduction				x								

5.3 PETROCHEMICAL Pilot

The PETROCHEMICAL Pilot revolves around the optimization of monoethylene glycol production using ethylene oxide (EO), a flammable colourless gas with a sweet smell. The overarching objective is to enhance operational efficiency by reducing steam consumption through adjustments in temperature and pressure. Key performance indicators (KPIs) include a targeted 5% decrease in steam consumption, a parallel reduction of 5% in CO2 emissions from the EO stripper, and a 5% decrease in the unit cost of the EO stripper. These objectives are envisaged through specific measures such as manipulating the EO stripper overhead temperature, lowering the EO column pressure, and controlling the EO content in the stripper's bottom. The Pilot's scope is concentrated on the product recovery steps, encompassing absorbing and stripping processes, with real-time monitoring facilitated by physical sensors displaying data on DT screens. Augmenting this, artificial intelligence analytics will be employed to fortify predictive capabilities and optimize decision-making, concurrently mitigating steam consumption. In line with circularity principles, waste CO2 from the EO reactor and H2 from the Steam-Methane Reforming Unit will be utilized for dimethyl ether (DME) production. Despite the absence of an on-site DME plant, Aspen engineering suit models will simulate the DME production process using historical CO2 disposal flow data. The resultant DME is slated for use as a combustion fuel for steam generation, providing an environmentally conscious alternative to natural gas in the steam generator unit and thereby completing the circularity of the production process.

5.3.1 Requirements vs identified technologies

From WP4 perspective, i.e., considering data availability, this Pilot is very different from the other ones. The main difference is on the data source availability, which is extremely high thanks to sensor data on-premises. The need of a Data Space, as per current Pilot standpoint, rises in the context of exploiting external AI services with collected data.

- **Data Quality:** In PETROCHEMICAL Pilot, data sources are located in the plant, available as raw sensor data. A series of pre-processing steps, like normalization, feature selection, scaling, handling of imbalanced data, clearing and filling are needed before having a well-built dataset for AI use.
- **Data Confidentiality:** Secure access to their own production data from unauthorized access is a requirement expressed in the Pilot agreement.
- **Data Interconnectedness:** The Pilot plant is composed of several systems that produce data. To leverage their full potential and build high-quality data it is necessary to achieve high interconnection between datasets.
- **Connectivity:** The use of real-time data from the plant towards external AI systems need that connectivity requirements are largely satisfied, especially in conditions where real-time predictions are necessary to guarantee the correct execution of the production processes.

- **Data Filtering, Aggregation and Storage:** The need for pre-processing of plant data by a possible partner entails the need to define separate roles and locations where the data reside. While the pre-processing steps can be carried out at TEKNOPAR's site due to the access to SOCAR's data from a Data Space, it may be necessary for the data and results to be stored at SOCAR's site.
- **Data Monetization and Business Model:** One possible scenario that could open from the Project is the exploitation of data and/or AI services results with openness to business. Although the Project itself is thought to provide an open-source technical architecture to support Pilots, the use of data and services may undergo usage fees based on Data Space participants' agreements.
- **Data Sovereignty:** This requirement comes directly from the above-mentioned ones. Whether a data business model is exploited, or a participant wants to share its data with specific restrictions, data sovereignty was identified as a key requirement for PETROCHEMICAL Pilot.
- **Trustworthiness:** To allow the correct utilization of data, especially with real-time applications, it must be ensured that every barrier that may delay or deny the correct usage of data must be broken down.
- **Information Traceability:** The core process that PETROCHEMICAL Pilot wants to optimize is the re-utilization of CO2 for DME production, a process that requires data from several system to be tracked to ensure its correct execution and evaluate the expected KPIs.
- **Close Loop Material Flow:** The PETROCHEMICAL Pilot differentiates from other product-driven industries for the closed-loop material flow. While in other Pilots' materials are recovered in the EoL of products not suitable for remanufacturing, here the aim is recovering any production waste and reutilizing it to create a new product without leaving the plant.
- **Waste Reduction:** In the traditional production flow, CO2 is a waste that is recovered by the plant and released in the atmosphere. With Circular TwAIn Project, the aim is to reduce its production and re-utilize it to give it a new purpose with high environmental advantages.

Table 3: PETROCHEMICAL Pilot mapping over identified requirements and technologies

Requirements \ Data Space Components	Industrial Data Platform	TRUE Connector	Eclipse Dataspace Connector	Asset Administration Shell	Digital Product Passport	Identity Provider	Certification Authority	DT Registry	Data Vocabulary	IDS Metadata Broker	Digital Clearing House	Usage Control
Data Requirements												
Quantity	x											x
Quality	x			x					x			
Confidentiality	x	x	x			x	x					x
Portability	x	x	x	x	x			x	x			
Standardization	x			x	x			x	x	x		
Interconnectedness	x					x		x	x	x		
Recycling				x	x							
Data Space Technical Requirements												
Connectivity	x	x	x	x		x	x			x	x	
Data Filtering & Aggregation	x			x								
Data Storage	x							x				
Data Transaction	x	x	x			x	x				x	x
Decision Support or Actuation	x	x	x									
Data Treatment	x											x
Data Space Business Requirements												
Data Monetization												
Data Business Model				x					x			
Data Sovereignty	x	x	x			x	x				x	x
Data Discovery								x	x	x	x	
Trustworthyness	x	x	x	x	x	x	x				x	
Technical Requirements For Circularity												
Material Traceability					x							
Information Traceability					x						x	
Information and Material Sharing					x							
Business Requirements For Circularity												
Close Loop Material Flow				x								
Waste Reduction				x								

6 Conclusion and Future Outlook

D4.3 - "*Data Integration and Validation report – 1st version*" presents the initial outputs of T4.5 "Data Integration, Testing and Technical Validation" activities.

The task assesses the validity of the work performed over the data to feed the AI-enabled Digital Twins developed in WP5 and to enable the data flows in the Pilots UCs execution, and with the intention to push on the applicability of the new technologies here discussed (i.e., Data Spaces, Asset Administration Shell, Digital Product Passport, Digital Twin Registry) advices some scenarios to boost on circularity and sustainability process and product manufacturers value chains.

The major outcome of the deliverable (i.e. the third and last step of the first phase of the methodology described in Section 2) lays on the Pilot Mapping tables (Table 1 for the WEEE Pilot. Table 2 for the BATTERY Pilot, and Table 3 for the PETROCHEMICAL Pilot): these tables portrait the connection between the requirements reported in Section 3 and the technologies listed in Section 4 with the application domain (i.e., WEEE, BATTERY, PETROCHEMICAL) and are expected to be considered as a pattern for the WP4 tasks to manage the development, deployment and validation of the respective technologies. Further, the table rows coloured in green are aimed to highlight which are the relevant requirements for each the pilot, linked also to the technologies candidates to cover the expectations of the UCs.

As per the Methodology defined in Section 2, the second version of this deliverable (planned for M36) is expected to include:

1) A mapping between the final tools developed and the need to adopt/adapt/develop a certain technology/asset/protocol,
2) A portrait of what has been deployed where, including insights of the internal iterations required to cover all Pilots' expectations,
3) The final validation of WP4 results,
4) A series of recommendations for future working opportunities in the data field in the creation of services to support Circular and Sustainable Economy in Manufacturing.

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